بسم الله الرحمن الرحيم

Sudan University of Science and Technology

College of Graduate Studies

Soil characterization and Land Suitability Assessment for El Fasher Agricultural Research Farm North Darfur State

تشخيص التربة وتقويم صلاحية الأرض في مزرعة البحوث الزراعية بالفاشر – ولاية شمال دارفور

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By:

Mahmoud Hashim Mohamed Tahir

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Supervisor:

Dr. El-Abbas Doka Mohamed Ali

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[redacted] (وقل اعملوا فسيرى الله عملكم ورسوله والمؤمنون وستردون إلى عالم الغيب
[redacted] والشهادة فينبئكم بما كنتم تعملون)

صدق الله العظيم

سورة التوبة الآية (105)

Dedication

To my Family,

To my Teachers,

To my Friends,

Acknowledgements

First of all, I render my gratitude and praise to the Almighty Allah.

I wish to express my sincere gratitude to my supervisor **Dr. El-Abbas Doka Mohamed Ali** for his helpful guidance, encouragement and supervision of this research. Last but not least, thanks are extended to my family, specially my brothers for financing my studies and helping me in many ways to finish my study.

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List of acronyms

ARC	Agricultural Research Coporation
CEC	Cation exchange capacity
EC	Electrical conductivity
ESP	Exchangeable sodium percentage
FAO	Food and Agriculture Organization of the United Nations
GTZ	Deutsche Gesellschaft for Technische Zusammenarbeit
GFE	Gesellschaft for Forschung und EntwicklungsproJektlerung
HTS	Hunting Technical Services
ISRIC	International Soil Reference and Information Centre
ISSS	International Society of Soil Science
IUSS	International Union of Soil Sciences
ILRI	Institute for Land Reclamation and Improvement
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
NSCC	National Soil Conversation Service
SAR	Sodium adsorption ratio
SALIS	Soil and Land Information system
SESACO	Sesame coordinators
USDA	United States Department of Agriculture
UNESCO	United Nations Educational, Scientific, and Cultural Organization
WRB	World Reference Base for Soil Resources

Abstract

This study was conducted in the El-Fasher Agricultural Research Farm which is located in North Darfur State latitude 13:38’ Degree north and longitudes 25:19’degree west. The main road which connects EI-Fasher to Kutum and other important towns runs beside the farm area. The farm is dominated by flat topography within the undulating sandy plain. The climate of the study area is arid and the main types of vegetation in the study area are Qoz vegetation . The water resources were Surface water and underground water. The major land use types are traditional farming (rain fed) and animal breeding.

This study aimed to characterize the soils EL-Fasher Agricultural Research Farm and show their variability. As well, the study indicated the suitability of the land for some selected crops and recommended the proper management practices. The Gridsoil survey method was followed in this study which involved field descriptions and taking of representative soil samples at intervals of (100cm) apart, Five soil profile ware dug to 200cm depth, soil samplles Collected and complete routine analysis were carried to show the chemical and physical.

Four different soil physiographic units have been identified which are the slightly higher Medium and Coarse Sand (**SL**) and Fine Sand (**SH**), the Sand dune (**SD**), and the flat lower Sand plain (**SP**).The Farm is generally composed of one map unit with consociations of minor inculcations of similar sandy soils. The results of field description and laboratory analysis revealed that the soil of the farm has high filtration due to the texture classes with fertility limitation. According to land suitability system the study rated the soils in class two with fertility limitation (S2f), and class (S3ft) with fertility and moisture deficiency (S3fm).

The study recommended the soil of the EL-Fasher Agricultural Research Farm should have proper additions of organic matter which leads to building of healthy and high quality soils which will have great positive influence on plants. Applying a good system of irrigation methods with good quality water in appropriate time is required for these sandy soils. Results and recommendations of the trials and experiments carried on this farm should only be applied to similar sandy soils. For other types of soils in the state, experiments and trials could be carried on farmer’s fields.

المستخلص

أجريت هذه الدراسة للتربة في مزرعة بحوث الفاشر بمدينه الفاشر ولاية شمال دارفور الواقعة بين خط العرض 1338درجة شمالا وخط طول 2519 درجه غربا. الطريق الرئيسي الذي يربط بين مدينه الفاشر ومدينه كتم يمر بجانب المزرعة، طبوغرافية الأرض بالمنطقة منبسطة تقريبا. المناخ الجاف هو السائد في المنطقة كما توجد بالمنطقة نباتات القيزان. مصادر المياه بالمنطقة سطحيه وجوفيه.استخدام ارض المزرعة في الزراعة التقليدي(مطري) وتربيه حيوان. تهدف هذه الدراسة لمعرفة خصائص التربة بمزرعة بحوث الفاشر وعرض اختلافاتها وتقييم درجة صلاحيتها.بالإشارة لبعض المحاصيل والتوصية بعمليات الإدارة الملائمة.

تم تطبيق طريقة الحصر الشبكي بهذه الدراسة وتضمنت الوصف الحقلي واخذ عينات التربة التمثيلية بالبريمة تبعد كل منها 100 متر كما تم حفر خمسة قطاعات بعمق (200سم) عينات التربة تم جمعها لإتمام التحاليل الفيزيائية والكيميائية وعرضها.

وقد تم تحديد أربع وحدات جيومورفلوجية مميزه للتربة وهي رمل خشن (**SL**)، رمل ناعم (**SH**)،كثبان رمليه(**SD**) وسهل رملي(**SP**). عموما تتكون المزرعة من وحدة خريطة واحدة التربة الرملية المتشابهة، نتائج الوصف الحقلي والتحليل المعملي أثبتت أن تربه المزرعة ذات نفاذية عاليه بسبب نوع القوام مع وجود مشكله الخصوبة. بناءا على نظام تحديد صلاحية الأراضي قدرت الدراسة أراضي المزرعة ذات صلاحية متوسطه(S2) لوجود محدد الخصوبة (S2f)، وصلاحية هامشيه(S3) لوجود محددين الخصوبة والنفاذية (S3ft).

أوصت الدراسة بإضافة المادة العضوية لتربة مزرعة بحوث الفاشر بالكمية المناسبة لتحسين جوده وصحة التربة، تطبيق نظام ري جيد ومياه ذات نوعيه جيدة في الوقت المناسب، تطبيق النتائج والتوصيات من المزرعة وفي ترب مشابهه ومماثلة للمزرعة, يجب أن يكون للتربة من المزرعة بحوث الفاشر الزراعية الإضافات المناسبة من المواد العضوية التي تؤدي إلى بناء التربة جودة صحية وعالية والتي سيكون لها تأثير إيجابي كبير على النباتات, تطبيق نظام جيد للطرق الري بمياه ذات نوعية جيدة في الوقت المناسب والمطلوب لهذه التربة، وينبغي تطبيق النتائج والتوصيات من التجارب والتجارب التي تقوم على هذه المزرعة في التربة المماثلة لها في مزارع المزارعين.

CHAPPTER ONE

INTRODUCTION

1.1 Background

Soils differ greatly in their morphological, physic-chemical and mineralogical properties. These differences affect crop response to management inputs. Improper use of soils may reduce yields and as well aggravate degradation. it is, therefore, essential to understand the soil to ensure suitable sustainable agriculture and proper conservation.

The soil differences are due to variations in soil forming factors and processes operating on different parent materials, under different climatic, topographic, and biological conditions over varying periods of time (Soil survey Staff, 1993). Different soil types support different land use and require different management options for sustainable productivity (Ogunkunle, 1986).According to (Fagbami, 1990), the diversity nature of soil is a major reason behind allocation of land to wrong uses. Soil characterization and classification contribute to the alleviation of the adverse effect of soil diversity and aid precision agriculture. Soil characterization and classification is the main information source for precision agriculture, land use planning and management (Ogunkunle, 1986). This is because characterization and classification provide information for the understanding of the micro-morphological, physical, chemical, mineralogical and microbiological properties of the soil (Ogunkunle, 1986).

A soil survey describes the characteristics of the soils in a given area, classifies the soils according to a standard system of classification, plots the boundaries of the soils on a map, and makes predictions about the behavior of soils. The different uses of the soils and how the response of management affects them are considered in designing and carrying out the survey. The information collected in a soil survey helps in the development of land-use plans and evaluates and predicts the effects of land use on the environment (USDA.1993).In agricultural research, it turn to be a fundamental necessity to the soil of the research plots and field so as to transfer the research finding on them to similar regional soil of a like climate under the specified management packages.

1.2 Objectives of the study

The objectives of this study are:

1. To characterize the physical and chemical properties of the soils and show their variability and distribution in the Agricultural Research Farm at El Fasher.
2. To determine the land suitability classes and their limitations (subclasses) for growing of local and adapted crops in similar soils.
3. To provide guidelines for use and management of the farm soils and similar soils in the State to investigate how much the research farm soils are representative of the surrounding soils.
4. Soils of the farmers so as to extend soil related research results to local farmers.

1.3 Hypothesis

The hypothesis guiding this research study at El-fasher research Farm could be described as follows:

- Absence of detailed information on the soils of Farm.
- The soils of the farm might be similar to the surrounding soils and other dominant soils of the state.
- Soil management practices based on soil properties need to be established based on soil properties of El-Fasher research farm to guide the extension officers so as to advise local farmers.
- Inappropriate land use and management practices lead to inefficient exploitation and degradation the land resource which consequently results in low productivity and destruction of- the land resource

CHAPTER TWO

ENVIRONMENTAL SETUP

2.1 Location and extent

The study area is located in North Darfur State, west of El-Fasher town the state capital and lies within El-Fasher Locality. The main road which connects EI-Fasher to Kutum Locality runs beside El- Fasher Agricultural Research Farm area.

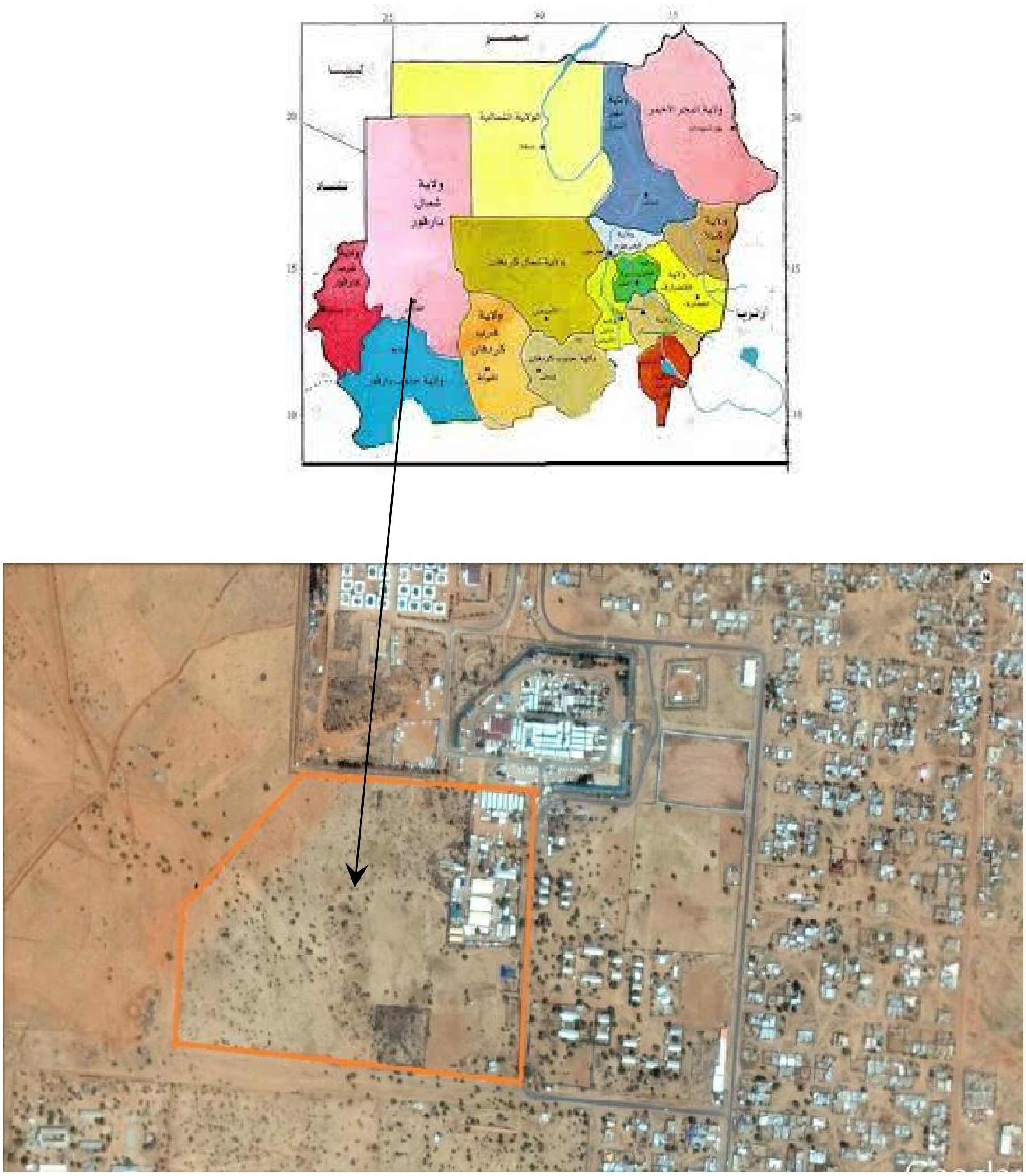


Figure 2. 1: Location map of El-Fasher Agricultural Research Farm

2.2 Geology and geomorphology

Block faulting and warping are the two events since the Pre-Cambrian which have a profound effect on the geology of the region and probably associated with the formation of the great Rifts of East Africa and outburst of volcanic activity in Tertiary times. The faulting and warping created a number of basins of deposition which have been filled with fluviatile, often coarse sediments (Hunting Technical Services, 1976).

The Pre-Cambrian Basement complex is covered by sandy cross-bedded continental sedimentary rocks (the Nubian sandstone formation).The sediments that later formed the Nubian Sandstone formation were deposited across a broad plains of western Sudan particularly at Kordofan and Darfur regions.

2.3 Climate

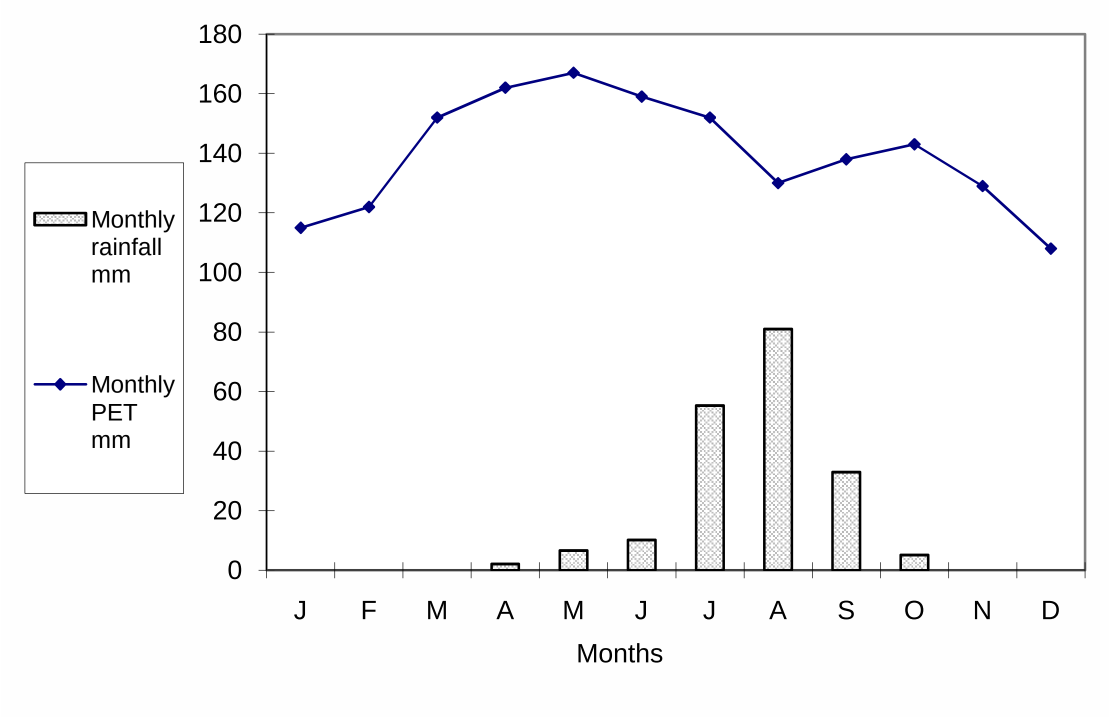
Climatic Zones were proposed for Sudan by (Van der Kevie 1976). This proposal was primarily based on water balance, using monthly rainfall and potential evapotranspiration data. Kevie pointed that the differentiating criteria are significant for agriculture, whilst the zones also correspond rather well with vegetation zones.

The definitions of the major zones have been adopted for Papadakis, but certain amendments were made e.g. in some of the dry climate zones and the dry monsoon zone, subdivisions were made based on lower temperature in winter. The dry zones were also divided in areas with winter or summer rainfall, or with no marked seasons.
However, in consequence the study area lies within the major arid zone. Table (2.1) provides a summary for sub-divisions.

Table 2. 1: Climatic Factors of the study area (Van der Kevin 1976)

ClimaicZone (Sub-Divisions of arid)	Humid months	Dry months	Growing season	Average annual rainfall mm	Mean max. Temp. In Hot month	Mean Max. Temp.in coldest month	Diagnostic characterization
locality, summer rain, cool winter	0	10-11	1-2	225-400	40-42	8-13	Rw=0.5.-1.0WTc< 13.

The rain falls mainly in the months June-August. Mean minimum temperature of the coldest month (January) is 8-13^{o} C which makes this climate more suitable for winter crops that need relatively low night temperatures, such as wheat, haricot beans, broad beans, potatoes and a number of temperate climate vegetables. The climate is also quite suitable for irrigated citrus.



Source: Doka, 2005.

Figure 2. 2: Rainfall and potential evapotranspiration for El Fasher

Source: Soil survey report of Wadi Abu Hamra project, 2005

2.4 Vegetation

The degradation forms resulting from drought, over cultivation, overgrazing, and clearing of woodland have changed the natural vegetation to such an. extent that a zonation of natural plant associations is rendered entirely questionable.

The occurrence, type and distribution of natural vegetation within an area are controlled by water availability a prime factor of climate, Ethology and landforms. Vegetation cover in the study area is of sparse to densely distribution. The vegetation has been greatly affected in the last three decades by land use practices and drought. The several attempts to make vegetation zones were primarily based on either rainfall amount or soil-landform type (Ibrahim, F. 1984).

The dominant vegetation types in the area is Qoz Vegetation are: *Acacia nubica* (Al laot), *Maerua erassifolin* (Al sareh), *Acacia tortilis,* (Alseya.1), and *Acacia millafera* (At 'Kill-) as individual or small groups' stands. *Aristida sieberna* (Gaw), *Aristida plumose* (Bayad), *Blepharis linariUblia* (Begheil), *Eirgrostis Terrnula* (Al banu) and *Tribulustrrestris* (Dereisa) are the dominant grasses.

Figure 2. 3: Qoz Vegetation in the study area (*Maerua erassifolia* (Al sareh).

2.5 Hydrology (Water Resources)

2.5.1 Surface water

The main surface hydrologic system in the study area is rain fallduring the rainyseason.

2.5.2 Underground water

Two source of underground water in the study area are:

1- Qoz Sands

The Qoz sands are considered to be groundwater free. Rainwater either evaporates or due to the good permeability of the sands, drains away to the underlying formations (GTZ-GFE-1989).

2- Nubian Sandstone

The Nubian Sandstone is the only aquifer in the area capable of storing and yielding significant and reliable volumes of water . In the study area, the major sandstone basins with a high groundwater potential exist (e.g. Shagera Basin). In general, the groundwater levels in the Nubian Sandstone range between 45 to 100 m below surface (GTZ-GFE-1989).

2.6 Major land use type

The main occupations in the area are.

- Traditional farming (rain fed).
- Traditional animal breeding.

Some sedentary inhabitants practice rain fed cultivation and livestock grazing. Due to poor soil characteristic in some parts and lack of dependable source of water, cultivation is discontinuous. Limited traditional rainfed is practiced to grow millet, sorghum and water Melons. Beside rain fed cultivation, Cattle, goats and sheep are raised in large numbers. Tree-felling and wood cutting for fuel and building purposes dominate as an activity. In Qoz land rainfed cultivation (shifting) is practiced: The main crops grown include: millet, sesame, groundnuts and water melons. In the rest of the uncultivated Qozland animals of sedentary tribes are grazed (Lebon, J.H.G & V.C, Robertson, 1961).

2.7 Population Activities

At urban centers the populations are mainly private sector, government employers, organization employers, but at rural areas they are mainly farmers and pastoralists. In the agricultural research farm at El Fasher most of the farm land is used for research trials but some parts were allotted for the staff members to grow some crops during rainy season.

2.8 Infrastructure

El-fasher, the capital of North Darfur is connected with a main asphalt federal road (Western Salvation Road) to Omdurman through North Kordofan and White Nile States. El Fasher is also connected with other federal roads going to capital towns; Nyala (South Darfur), Zalingie (Central Darfur) and Geneina (Western Darfur). Mainy other vital roads connect El fasher to Kutum and other important towns.

CHPTER THREE

LITRETURE REVIEW

3.1 Background

The vast importance of the soil in the development of varies system agricultural and types of civilizations has long been recognized but it is only within the last few decades that soil as such have been studied in a scientific manner. During thousands of years mankind has looked upon soils mainly from the utilitarian point of view, today it is being realized more and more, that the soil parse is worthy of scientific study. Theoretical research and thought, there is every reason to believe that any advance in the fundamental knowledge of soils will immediately stimulate practical phases of soil investigations (Michael E. R, 2012).

3.2 Soil Forming Factors

Soil is a 3-dimensional body with properties that reflect the impact of (1) parent material, (2) climate, and (3) topography on the soil's (4) Soil Living Organisms (5) time. The nature and relative importance of each of these five 'soil forming factors' vary in time and in space. With few exceptions, soils are still in a process of change; they show in their 'soil profile' signs of differentiation or alteration of the soil material incurred in a process of soil formation or 'pedogenesis' (Driessen *et al*, 2001).

3.2.1 Soil parent material

The Material from which soil forms is called parent material. It includes: weathered primary bedrock; secondary material transported from other locations, namely colluviums and alluvium; deposits that are already present but mixed or altered in other ways old soil formations, organic material; and anthropogenic materials, such as landfill or mine waste, (Milford H.B. *et al*, 2001).

Soils that develop from their underlying parent rocks are called "residual soils", and have the same general chemistry as their parent rocks. The soils found on mesas, plateaus and plains are residual soils but few other soils are residual, most soils derive from transported parent materials that have been moved many miles by wind, water and gravity, Aeolian processes are capable of moving fine sand and silt many hundreds of miles .forming loess soils, common in the Midwest of North America and in central Asia clay is seldom moved by wind as it forms stable aggregates cumulate parent material includes peats and mucks and may develop in place from plant residues that have been preserved y the low oxygen content of a high water table. Weathering is the first stage in the transforming of parent material in to soil material. In soil forming from bedrock- a thick layer of weathered material called saprolite may form. Coprolite is the result of weathering processes that include: hydrolysis (the division of a mineral solution of minerals in water with resulting cation, anion, pairs), and physical processes that include freezing and thawing, the mineralogical and chemical composition of the primary bedrock material, its physical features, including grain size and degree of consolidation, plus the rate and type of weathering, transforms the parent material into the different mineral components of soils. Texture, pH and mineral constituents are inherited by a soil from its parent material, (Milford, H.B. *et al*, 2001).

3.2.2 Climate

Soil formation greatly depends on the climate, and soils show the distinctive characteristics of the climate zones in which they form, temperature and moisture affect the rate of weathering and leaching, wind moves sand and smaller particles, especially in arid regions where there is little plant cover.

The type and amount of precipitation influence soil formation by affecting the movement of ions and particles through the soil, and aid in the development of different soil profiles, the effectiveness of water in weathering parent rock material depends on seasonal and daily temperature fluctuations, cycles of freezing and thawing constitute an effective mechanism that breaks up rocks and other consolidated materials, temperature and precipitation rates affect vegetation cover, biological activity, and the rates of chemical reactions in the soil (Gove Hambidge, 1941).

3.2.3 Topography

The topography or relief characterized by the inclination of the surface determines the rate of Precipitation runoff and rate of formation and erosion of the surface soil profiles; steep slopes allow rapid runoff and erosion of the top soil profiles and little mineral deposition in lower profiles. Depressions allow the accumulation of water, minerals and organic matter and in the extreme; the resulting soils will be saline marshes or peat bogs, intermediate topography affords the best conditions for the formation of an agriculturally productive soil, (Gove Hambidge, 1941).

3.2.4 Soil Living Organisms

Plants, animals, fungi, bacteria and humans affect soil formation, animals and microorganisms mix soils as they form burrows and pores, allowing moisture and gases to move about. In the same way, plant roots open channels in soils; plants with deep taproots can penetrate many meters through the different soil layers to bring up nutrients from deeper in the profile, plants with fibrous roots that spread out near the soil surface have roots that are easily decomposed, adding organic affect chemical exchanges between root and soil and act as a reserve of nutrient.

Human can impact soil formation by removing vegetation cover with erosion as the result they can also mix the different soil layer. Restarting the soil formation process as less weathered material is mixed with the more developed upper layers. Some soils may contain up to one million species of microbes per gram, most of those species being unknown, making soil the most abundant ecosystem on earth, Vegetation impacts soils in numerous ways.

It can prevent erosion caused by excessive rain and the resulting surface runoff, plants shade soils, keeping them cooler and slowing evaporation of soil moisture, or conversely, by way of transpiration, plants can cause soils to lose moisture, plants can form new chemicals that can break down or build up soil particles, the type and amount of vegetation depends on climate, land form topography, soil characteristics, and biological factors. Soil properties such as density, depth, chemistry, pH, temperature and moisture greatly affect the type of plants that can grow in a given location. Dead plants and dropped leaves and stems fall to the surface of the soil and decompose, there; organisms feed on them and mix the organic material with the upper soil. Layers these added organic compounds become part of the soil formation process, (Copley and Jon, 2005).

3.2.5 Time

Time is a factor in the interactions of all the above, over time, soils evolve features dependent on the other forming factors. Soil formation is a time-responsive process that is dependent on how the other factors interplay with each other. Soil is always changing. It takes about 800 to 1000 years for a 2.5 cm thick layer of fertile soil to be formed in nature, for example, recently deposited material from a flood exhibits no soil ’development because there has riot been enough time for soil-forming activities.

The original soil surface is buried, and the formation process must begin anew for this deposit, the long periods over which change occurs and its multiple influences mean that simple soils are rare, resulting in the formation of soil, while soil can achieve relative stability of its properties for extended periods, the soil life cycle ultimately ends in soil conditions that leave it vulnerable to erosion, despite the inevitability of soil retrogression and degradation, most soil cycles are long and productive. Soil-forming factors continue to affect soils during their existence, even on "stable" landscapes that are long-enduring, some for millions of years, materials are deposited on top and materials are blown or washed from the surface, with additions, removals and alterations, soils are always subject to new conditions. Whether these are slow or rapid changes depend on climate, landscape position and biological activity (Copley and Jon, 2005).

3.3 Physical and chemical properties

Physical properties are those that can be observed without changing the identity of the substance, the general properties of matter such as color, density, hardness, are examples of physical properties. Properties that describe how substance changes into a completely different substance are called chemical properties, flammability and corrosion oxidation resistance are examples of chemical properties. .

The difference between a physical and chemical property is straightforward until the phase of the material is considered. When a material changes from a solid to a liquid to a vapor it seems like them become a difference substance, however, when a material melts, solidifies, vaporizes, condenses or sublimes, only the state of the substance changes, consider ice, liquid water, and water vapor,. they are all simply H_2O, phase is a physical property of matter and matter can exist in four phases, solid, liquid, gas and plasma.

3.3.1 Physical Properties of soil

The physical properties of the soil are its texture, structure, density, porosity, consistency, temperature and color, these determine the availability of oxygen in the soil and ability of water to infiltrate and be held in the soil, soil texture, characterized by the different soil particles, called soil "separates" sand, silt and clay is the relative proportion of those three.

Larger soil structures are created from the separates when iron oxides, carbonates, clay and silica with the organic constituent humus, coat particles and cause them to adhere into relatively stable secondary structures called "pds", soil density, particularly bulk density, is a measure of the soil compaction. Soil porosity consists of the part of the volume occupied by air and water, consistency is the ability of soil to stick together, soil temperature and color are self-defining (Alfred Sefferud 1957).

3.3.1.1 Texture

The mineral components of soil are sand, silt and clay, and their relative proportions determine a soil's texture. Properties that are influenced by soil texture include porosity, permeability, infiltration, shrink-swell rate, water-holding capacity, and susceptibility to erosion. In the illustrated USDA textural classification triangle, the only soil in which neither sand and silt nor clay predominates is called "loam". While even pure sand, silt or clay may be considered a soil, from the perspective of food production a loam soil with a small amount of organic material is considered ideal.
The mineral constituents of a loam soil might be 40% sand, 40% silt and the balance 20% clay by weight. Soil texture affects soil behavior, in particular its retention capacity for nutrients and water (Nyle and Ray 2009).

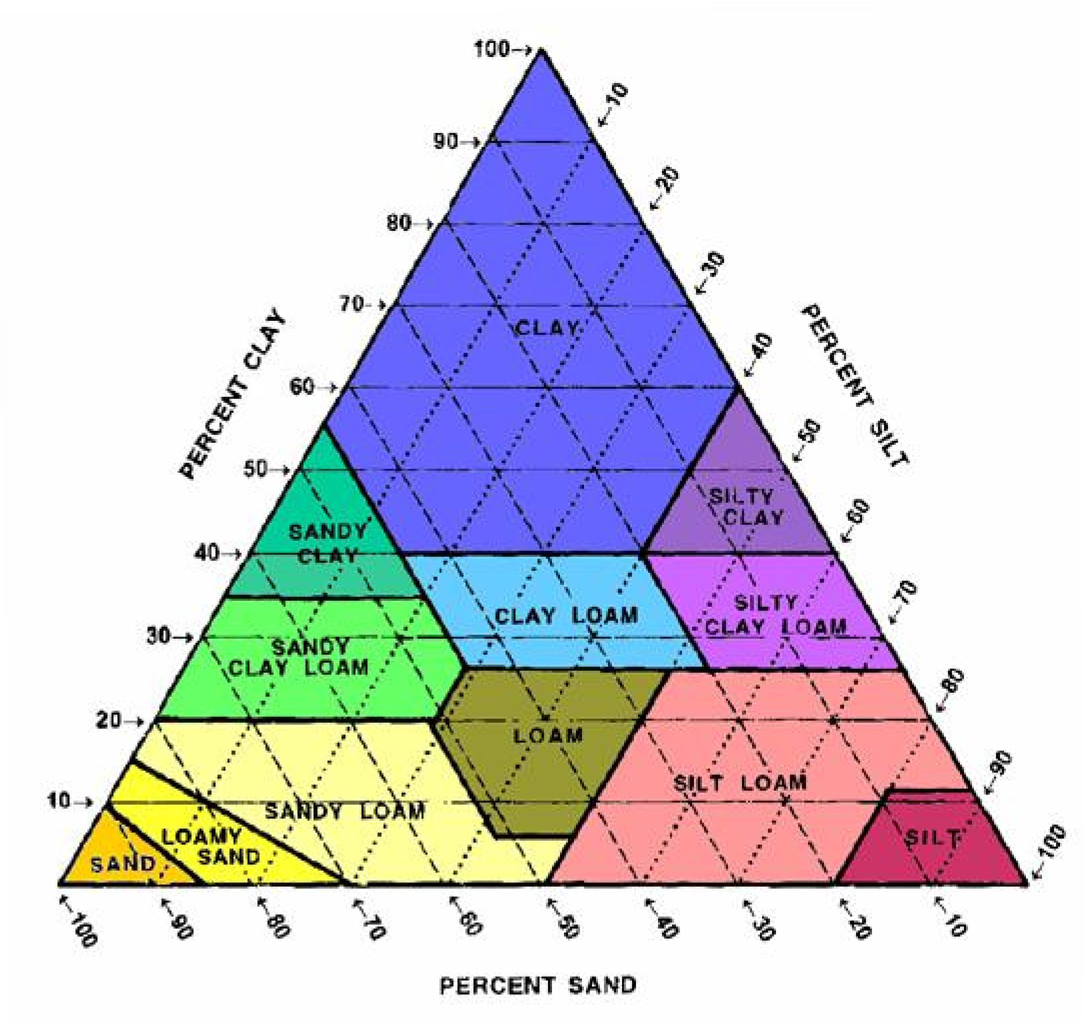


Figure 3.1: Texturtringle. as used by the USDA (Soil Survey Division Staff, 1993)

Sand and silt are the products of physical and chemical weathering of the parent rock, clay, on the other hand, is a product of the precipitation of the dissolved parent rock as a secondary mineral. It is the large surface area to volume ratio (specific surface area) of soil particles and the unbalanced ionic charges within those that determine their role in the cation exchange capacity of soil, and hence its fertility.

Sand is least active, followed by silt; clay is the most active. Sand's greatest benefit to soil is that it resists compaction and increases a soil's porosity. Silt is mineralogical like sand but with its higher specific surface area it is more chemically active than sand. But it is the clay content of soil, with its very high specific surface area and generally large number of negative charges that gives a soil its high retention capacity for water and nutrients. Clay soils also resist wind and water erosion better than silty and sandy soils, as the particles bond tightly to each other.Sand is the most stable of the mineral components of soil; it consists of rock fragments, primarily quartz particles, ranging in size from 2.0 to 0.05 mm (0.0787 to 0.0020 in) in diameter. Silt ranges in size from 0.05 to 0.002 mm (0.002 to 0.00008 in). Clay cannot be resolved by optical microscopes as its particles are 0.002 mm (7.9×10^{-5} in) or less in diameter. In medium-textured soils, clay is often washed downward through the soil profile and accumulates in the subsoil.

Soil components larger than 2.0 mm (0.079 in) are classed as rock and gravel and are removed before determining the percentages of the remaining components and the texture class of the soil, but are included in the name. For example, a sandy loam soil with 20% gravel would be called gravelly sandy loam. When the organic component of a soil is substantial, the soil is called organic soil rather than mineral soil. A soil is called organic if:

- Mineral fraction is 0% clay and organic matter is 20% or more
- Mineral fraction is 0% to 50% clay and organic matter is between 20% and 30%
- Mineral fraction is 50% or more clay and organic matter 30% or more (Donahue, *et al*, 1977).

3.3.1.2 Soil Structure

The clumping of the soil textural components of sand, silt and clay causes aggregates to form and the further association of those aggregates into larger units creates soil structures called pedoliths or peds. The adhesion of the soil textural components by organic substances, iron oxides, carbonates, clays, and silica, and the breakage of those aggregates from expansion-contraction, caused by freezing-thawing and wetting-drying cycles, shape soil into distinct geometric forms. The peds evolve into units which may have various shapes, sizes and degrees of development (Soil Survey Division Staff 1993).

A soil clod, however, is not a ped but rather a mass of soil that results from mechanical disturbance of the soil. Soil structure affects aeration, water movement, conduction of heat, plant root growth and resistance to erosion. Water, in turn, has its strongest effect on soil structure due to its solution and precipitation of minerals and its effect on plant growth.

Soil structure often gives clues to its texture, organic matter content, biological activity, past soil evolution, human use, and the chemical and mineralogical conditions under which the soil formed. While texture is defined by the mineral component of a soil and is an innate property of the soil that does not change with agricultural activities, soil structure can be improved or destroyed by the choice and timing of farming practices.

- Soil structural classes are defined as follows (Donahue, *et al*, 1977).

<u>Types</u>: Shape and arrangement of pads

1. *Platy*: Peds are flattened one atop the other 1–10 mm thick. Found in the A-horizon of forest soils and lake sedimentation.

2. *Prismatic and Columnar:* Prism like peds are long in the vertical dimension, 10–100 mm wide. Prismatic peds have flat tops, columnar peds have rounded tops. Tend to form in the B-horizon in high sodium soil where clay has accumulated.
3. *Angular and sub angular*: Blocky peds are imperfect cubes, 5–50 mm, angular has sharp edges, sub angular have rounded edges. Tend to form in the B-horizon where clay has accumulated and indicate poor water penetration.
4. *Granular and Crumb:* Spheroid peds of polyhedrons, 1–10 mm, often found in the A-horizon in the presence of organic material. Crumb peds are more porous and are considered ideal.

Classes: Size of peds whose ranges depend upon the above type

1. Very fine or very thin: <1 mm platy and spherical; <5 mm blocky; <10 mm prism like.
2. Fine or thin: 1–2 mm platy, and spherical; 5–10 mm blocky; 10–20 mm prism-like.
3. Medium: 2–5 mm platy, granular; 10–20 mm blocky; 20-50 prism-like.
4. Coarse or thick: 5–10 mm platy, granular; 20–50 mm blocky; 50–100 mm prism-like.
5. Very coarse or very thick: >10 mm platy, granular; >50 mm blocky; >100 mm prism-like.

Grades: Is a measure of the degree of development or cementation within the peds that results in their strength and stability.

1. Weak: Weak cementation allows peds to fall apart into the three textural constituents, sand, silt and clay.
2. Moderate: Peds are not distinct in undisturbed soil but when removed they break into aggregates, some broken aggregates and little un-aggregated material. This is considered ideal.
3. Strong:Peds are distinct before removed from the profile and do not break apart easily.
4. Structure less: Soil is entirely cemented together in one great mass such as slabs of clay or no cementation at all such as with sand.

At the largest scale, the forces that shape a soil's structure result from swelling and shrinkage that initially tend to act horizontally, causing vertically oriented prismatic peds. Clayey soil, due to its differential drying rate with respect to the surface, will induce horizontal cracks, reducing columns to blocky peds. Roots, rodents, worms, and freezing-thawing cycles further break the peds into a spherical shape.

At a smaller scale, plant roots extend into voids and remove water causing the open spaces to increase, and decrease physical aggregation size. At the same time roots, fungal hyphae and earthworms create microscopic tunnels that break up peds. At an even smaller scale, soil aggregation continues as bacteria and fungi exude sticky polysaccharides which bind soil into small peds. The addition of the raw organic matter that bacteria and fungi feed upon encourages the formation of this desirable soil structure.

At the lowest scale, the soil chemistry affects the aggregation or dispersal of soil particles. The clay particles contain polyvalent cations which give the faces of clay layers a net negative charge. At the same time the edges of the clay plates have a slight positive charge, thereby allowing the edges to adhere to the faces of other clay particles or to flocculate (form clumps). On the other hand, when monovalent ions such as sodium invade and displace the polyvalent cations, they weaken the positive charges on the edges, while the negative surface charges are relatively strengthened. This leaves a net negative charge on the clay, causing the particles to push apart, and by doing so to prevent the flocculation of clay particles into larger, open assemblages,
(CSS. 2012).

As a result, the clay disperses and settles into voids between peds, causing those to close. In this way the soil aggregation is destroyed and the soil is made impenetrable to air and water. Such sodic soil tends to form columnar structures near the surface, (CSS 2012).

3.3.1.3 Density

Soil particle density is typically 2.60 to 2.75 grams per cm^3 and is usually unchanging for a given soil. Soil particle density is lower for soils with high organic matter content, and is higher for soils with high Fe-oxides content. Soil bulk density is equal to the dry mass of the soil divided by the volume of the soil,it includes air space and organic materials of the soil volume. The soil bulk density of cultivated loam is about 1.1 to 1.4 g/cm^3 (for comparison water is 1.0 g/cm^3) (Johnson. *et al* 2013). Abbreviations

Soil bulk density is highly variable for a given soil. A lower bulk density by itself does not indicate suitability for plant growth due to the influence of soil texture and structure. A high bulk density is indicative of either soil compaction or high sand content. Soil bulk density is inherently always less than the soil particle density.

Table 3.1: Representative bulk densities of soils, the percentage pore space was calculated using 2.7 g/cm^3 for particle density except for the peat soil, which is estimated

Soil treatment and identification	Bulk Density g/cm^3	Pore space %
Tilled surface soil of a cotton field	1.3	51
Trafficked inter-rows where wheels passed surface	1.67	37
Traffic pan at 25 cm deep	1.7	36
Undisturbed soil below traffic pan, clay loam	1.5	43
Rocky silt loam soil under aspen forest	1.62	40
Loamy sand surface soil	1.5	43
Decomposed peat	0.55	65

Source: David, 1982.

3.3.1.4 Porosity

Pore space is that part of the bulk volume of soil that is not occupied by either mineral or organic matter but is open space occupied by either gases or water. Ideally, the total pore space should be 50% of the soil volume. The gas space is needed to supply oxygen to organisms decomposing organic matter, humus, and plant roots. Pore space also allows the movement and storage of water and dissolved nutrients. This property of soils effectively compartmentalizes the soil pore space such that many organisms are not in direct competition with one another, which may explain not only the large number of species present, but the fact that functionally redundant organisms (organisms with the same ecological niche) can co-exist within the same soil.(Johnson. *et al*, 2013).

Table 3.2: Categories of soil pores:

1	Coarse pores:	0.2 mm -200 microns
2	Medium pores:	200-20 microns
3	Fine pores:	20-2 microns
4	Very fine pores:	<2 microns

In comparison, root hairs are 8 to 12 µm in diameter. When pore space is less than 30 µm, the forces of attraction that hold water in place are greater than the gravitational force acting to drain the water. At that point, soil becomes water-logged and it cannot breathe. For a growing plant, pore size is of greater importance than total pore space.

A medium-textured loam provides the ideal balance of pore sizes. Having large pore spaces that allow rapid gas and water movement is superior to smaller pore space soil that has a greater percentage pore space. Soil texture determines the pore space at the smallest scale, but at a larger scale, soil structure has a strong influence on soil aeration, water infiltration and drainage (Donahue, Miller and Shickluna 1977). Tillage has the short-term benefit of temporarily increasing the number of pores of largest size, but in the end those will be degraded by the destruction of soil aggregation. Clay soils have smaller pores, but more total pore space than sand.

3.3.1.5 Consistency

Consistency is the ability of soil to stick to itself or to other objects (cohesion and adhesion respectively) and its ability to resist deformation and rupture. It is of approximate use in predicting cultivation problems and the engineering of foundations. Consistency is measured at three moisture conditions: air-dry, moist, and wet. In those conditions the consistency quality depends upon the clay content. In the wet state, the two qualities of stickiness and plasticity are assessed. A soil's resistance to fragmentation and crumbling is assessed in the dry state by rubbing the sample. Its resistance to shearing forces is assessed in the moist state by thumb and finger pressure. Finally, a soil's plasticity is measured in the wet state by moulding with the hand. Additionally, the cemented consistency depends on cementation by substances other than clay, such as calcium carbonate, silica, oxides and salts; moisture content has little effect on its assessment. The measures of consistency border on subjective compared to other measures such as pH, since they employ the apparent feel of the soil in those states.

The term is usually used to describe the soil consistency in three moisture states and a last consistency not affected by the amount of moisture is as follows:

- Consistency of Dry Soil: loose, soft, slightly hard, hard, very hard, extremely hard
- Consistency of Moist Soil: loose, very friable, friable, firm, very firm, extremely firm
- Consistency of Wet Soil: non-sticky, slightly sticky, sticky, very sticky; nonplastic, slightly plastic, plastic, very plastic
- Consistency of Cemented Soil: weakly cemented, strongly cemented, indurated requires hammer blows to break up (Donahue, *et al*, 1977).

Soil consistency is useful in estimating the ability of soil to support buildings and roads. More precise measures of soil strength are often made prior to construction.

3.3.1.6 Soil Color

Soil color is often the first impression one has when viewing soil. Striking colors and contrasting patterns are especially noticeable. The Red River (Mississippi watershed) carries sediment eroded from extensive reddish soils like Port Silt Loam in Oklahoma. The Yellow in China carries yellow sediment from eroding loess soils. Mollisols in the Great Plains of North America are darkened and enriched by organic matter. Podzols in boreal forests have highly contrasting layers due to acidity and leaching. In general, color is determined by the organic matter content, drainage conditions, and degree of oxidation.

Soil color, while easily discerned, has little use in predicting soil characteristics. It is of use in distinguishing boundaries within a soil profile, determining the origin of a soil's parent material, as an indication of wetness and waterlogged conditions, and as a qualitative means of measuring organic, salt and carbonate contents of soils. Color is recorded in the Munsell color system as for instance 10YR3/4 Dusky Red.

Soil color is primarily influenced by soil mineralogy. Many soil colors are due to various iron minerals. The development and distribution of color in a soil profile result from chemical and biological weathering, especially redox reactions. As the primary minerals in soil parent material weather, the elements combine into new and colorful compounds. Iron forms secondary minerals of a yellow or red color, organic matter decomposes into black and brown compounds, and manganese, sulfur and nitrogen can form black mineral deposits. These pigments can produce various color patterns within a soil. Aerobic conditions produce uniform or gradual color changes, while reducing environments (anaerobic) result in rapid color flow with complex, mottled patterns and points of color concentration (USDA 2008).

3.3.1.7 Soil Water

Water affects soil formation, structure, stability and erosion but is of primary concern with respect to plant growth. Water is essential to plants for four reasons:

- It constitutes 80%-95% of the plant's protoplasm.
- It is essential for photosynthesis.
- It is the solvent in which nutrients are carried to, into and throughout the plant.
- It provides the turgidity by which the plant keeps itself in proper position.

In addition, water alters the soil profile by dissolving and re-depositing minerals, often at lower levels, and possibly leaving the soil sterile in the case of extreme rainfall and drainage. In a loam soil, solids constitute half the volume, gas one-quarter of the volume, and water one-quarter of the volume of which only half will be available to most plants.

A flooded field will drain the gravitational water under the influence of gravity until water's adhesive and cohesive forces resist further drainage at which point it is said to have reached field capacity. At that point, plants must apply suction to draw water from a soil. When soil becomes too dry, the available water.(Richards & Richards 1957) is used up and the remaining moisture is unavailable water as the plant cannot produce sufficient suction to draw in the water. A plant must produce suction that increases from zero for a flooded field to 1/3 bar at field dry condition (one bar is a little less than one atmosphere pressure). At 15 bar suction, wilting percent, seeds will not germinate, plants begin to wilt and then die. Water moves in soil under the influence of gravity, osmosis and capillarity. When water enters the soil, it displaces air from some of the pores, since air content of a soil is inversely related to its water content.
The rate at which a soil can absorb water depends on the soil and its other conditions. As a plant grows, its roots remove water from the largest pores first. Soon the larger pores hold only air, and the remaining water is found only in the intermediate- and smallest-sized pores. The water in the smallest pores is so strongly held to particle surfaces that plant roots cannot pull it away.

Consequently, not all soil water is available to plants. When saturated, the soil may lose nutrients as the water drains. Water moves in a drained field under the influence of pressure where the soil is locally saturated and by capillarity pull to dryer parts of the soil. Most plant water needs are supplied from the suction caused by evaporation from plant leaves and 10% is supplied by "suction" created by osmotic pressure differences between the plant interior and the soil water. Plant roots must seek out water. Insufficient water will damage the yield of a crop. Most of the available water is used in transpiration to pull nutrients into the plant.

3.3.2 Chemical Properties of Soil

A soil test provides information about a soil's chemical properties; the soil test report indicates the levels of the various nutrient elements in our sample as well as soil pH, buffer pH, cation exchange capacity, base saturation and organic matter.

3.3.2.1 Essential Elements

There are thirteen essential mineral for plant growth, six of these are called major or macro elements because the plant uses them in rather large amounts, they are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S). Sometimes Ca, Mg and S are referred to as secondary elements because they are used in somewhat smaller amounts than N, P and K. Seven more are called minor, micro or trace elements, these are every bit as important as major elements, but are used in very small amounts, these elements include iron (Fe), Manganese (Mn), zinc (Zn), boron (B), copper (Cu), molybdenum (Mo) and chlorine (CD. Nickel (Ni) is accepted by many scientists as the 14th nutrient element derived from soils. In addition to mineral elements, carbon (C), hydrogen (H) and oxygen (0) are essential elements; plants take these elements from air and water. We don't apply fertilizer materials to the soil in order to supply C, H and 0, but our soil management practices have an effect on their availability. (Brady, N.C, .1974).

3.3.2.2 Cation Exchange Capacity (CEC)

Cation exchange capacity should be thought of as the soil's ability to remove cations from the soil water solution and sequester those to be exchanged later as the plant roots release hydrogen ions to the solution. CEC is the amount of exchangeable hydrogen cation (H+) that will combine with 100 grams dry weight of soil and whose measure is one milliequivalent per 100 grams of soil (1 meq/100 g). Hydrogen ions have a single charge and one-thousandth of a gram of hydrogen ions per 100 grams dry soil gives a measure of one milliequivalent of hydrogen ion. Calcium, with an atomic weight 40 times that of hydrogen and with a valence of two, converts to (40/2) x 1 milliequivalent = 20 milliequivalents of hydrogen ion per 100 grams of dry soil or 20 meq/100 g. The modern measure of CEC is expressed as centimoles of positive charge per kilogram (cmol/kg) of oven-dry soil.

Most of the soil's CEC occurs on clay and humus colloids, and the lack of those in hot, humid, wet climates, due to leaching and decomposition respectively, explains the relative sterility of tropical soils. Live plant roots also have some CEC (Donahue, *et al*, 1977).

3.3.2.3 Base Saturation

Richards, (1954), said that the cations Ca^{++},Mg^{++},K^{+} and H^{+}normally account for nearly all cations adsorbed on soil particles, although trace elements that are cations are also present in minute quantities. Ca^{l-F},me-, and IC^{-} are called bases and Fr and Ari- are acidic cations that lower soil pH, if all of the adsorbed cations are bases and none are acidic, there would be a 100% base saturation, and the soil pH would be about 7 (neutral) or above. In acid soils there are acid cations present and the per cent base saturation is less than 100. Besides having sufficient quantities of Ca, Mg and K, it is important that they be in balance with each other because an excess of one of these can suppress the uptake of another, as a general rule a Ca: Mg: K ratio of about 20:4:1 is desirable. When expressed as percent base saturation, desired levels are: Ca 65-80%; Mg 5-15%; and K 2-5%, (John, H, 1997).

3.3.2.4 Soil pH

Soil reactivity is expressed in terms of pH and is a measure of the acidity or alkalinity of the soil. More precisely, it is a measure of hydrogen ion concentration in an aqueous solution and ranges in values from 0 to 14 (acidic to basic) but practically speaking for soils, pH ranges from 3.5 to 9.5, as pH values beyond those extremes are toxic to life forms.

At 25 °C, an aqueous solution that has a pH of 3.5 has 10−3.5 moles H+ (hydrogen ions) per liter of solution (and also 10−10.5 mole/liter OH−). A pH of 7, defined as neutral, has 10−7 moles hydrogen ions per liter of solution and also 10−7 moles of OH− per liter; since the two concentrations are equal, they are said to neutralize each other. A pH of 9.5 has 10−9.5 moles hydrogen ions per liter of solution (and also 10−2.5 mole per liter OH−). A pH of 3.5 has one million times more hydrogen ions per liter than a solution with pH of 9.5 (9.5 - 3.5 = 6 or 106) and is more acidic.

The effect of pH on a soil is to remove from the soil or to make available certain ions. Soils with high acidity tend to have toxic amounts of aluminum and manganese. Plants which need calcium need moderate alkalinity, but most minerals are more soluble in acid soils. Soil organisms are hindered by high acidity, and most agricultural crops do best with mineral soils of pH 6.5 and organic soils of pH 5.5(Chang 1984).

In high rainfall areas, soils tend to acidity as the basic cations are forced off the soil colloids by the mass action of hydrogen ions from the rain as those attach to the colloids. High rainfall rates can then wash the nutrients out, leaving the soil pore. Once the colloids are saturated with H+, the addition of any more hydrogen ions or aluminum hydroxyl cations drives the pH even lower (more acidic) as the soil has been left with no buffering capacity. In areas of extreme rainfall and high temperatures, the clay and humus may be washed out, further reducing the buffering capacity of the soil. In low rainfall areas, un-leached calcium pushes pH to 8.5 and with the addition of exchangeable sodium, soils may reach pH 10. Beyond a pH of 9, plant growth is reduced. High pH results in low micro-nutrient mobility, but water-soluble cheated of those nutrients can supply the deficit. Sodium can be reduced by the addition of gypsum (calcium sulphate) as calcium adheres to clay more tightly than does sodium causing sodium to be pushed into the soil water solution where it can be washed out by an abundance of water (Donahue, *et al*, 1977).

3.3.2.5 Soil Salinity (Electrical Conductivity - ECe)

Electrical conductivity (EC) of a soil Solution or extract indicates the concentration of total soluble salts in solution-thus reflecting the degree of soil salinity. The unit of measurements called millimhos per centimeter (mmhos/cm) or deci-Siemen per meter (ds/m). The EC is reported to a standard temperature of 25°C**,** Salinity affects plants at all stages of development. And for some crops sensitivity varies from one growth stage to another. For example barley, wheat, and maize are more sensitive to salinity during early seedling growth than during germination or at advanced stages of growth and grain development (Maas, E.V and Hoffman, G.Z, 1977).

3.3.2.6 Soil solutions

Soils retain water that can dissolve a range of molecules and ions, these solutions exchange gases with the soil atmosphere, contain dissolved sugars, fulvic acids and other organic acids, plant nutrients such as nitrate, ammonium, potassium, phosphate, sulfate and calcium, and micronutrients such as zinc, iron and copper. These nutrients are exchanged with the mineral and humic component that retains them in its ionic state by adsorption. Some arid soils have sodium solutions that greatly impact plant growth, soil pH can affect the type and amount of anions and cations that soil solutions contain and that be exchanged between the soil substrate and biological organisms (Dan, 2000).

3.3.2.7 Soil organic matter

Soil organic matter is made up of organic compounds and includes plant, animal and microbial material, both living and dead. A typical soil has a biomass composition of 70% microorganisms, 22% macro fauna, and 8% roots. The living component of an acre of soil may include 900 lb. of earthworms, 2400 lb. of fungi, 1500 lb. of bacteria, 133 lb. of protozoa and 890 lb. of arthropods and algae (Foth, 1984).

A small part of the organic matter consists of the living cells such as bacteria, molds, and actinomycetes that work to break down the dead organic matter. Were it not for the action of these micro-organisms, the entire carbon dioxide part of the atmosphere would be sequestered as organic matter in the soil.

Chemically, organic matter is classed as follows:

1. Polysaccharides
2. cellulose
3. hemicelluloses
4. starch
5. pectin
6. Lignin
7. Proteins

Most living things in soils, including plants, insects, bacteria, and fungi, are dependent on organic matter for nutrients and/or energy. Soils have organic compounds in varying degrees of decomposition which rate is dependent on the temperature, soil moisture, and aeration. Bacteria and fungi feed on the raw organic matter, which are fed upon by amoebas, which in turn are fed upon by nematodes and arthropods. Organic matter holds soils open, allowing the infiltration of air and water, and may hold as much as twice its weight in water. Many soils, including desert and rocky-gravel soils, have little or no organic matter. Soils that are all organic matter, such as peat (Histosols), are infertile. In its earliest stage of decomposition, the original organic material is often called raw organic matter. The final stage of decomposition is called humus.

In grassland, much of the organic matter added to the soil is from the deep, fibrous, grass root systems. By contrast, tree leaves falling on the forest floor are the principal source of soil organic matter in the forest. Another difference is the frequent occurrence in the grasslands of fires that destroy large amounts of above ground material but stimulate even greater contributions from roots. Also, the much greater acidity under any forests inhibits the action of certain soil organisms that otherwise would mix much of the surface litter into the mineral soil. As a result, the soils under grasslands generally develop a thicker A horizon with a deeper distribution of organic matter than in comparable soils under forests, which characteristically store most of their organic matter in the forest floor (O horizon) and thin A horizon.

3.4 Soil degradation

Land degradation refers to a human-induced or natural process which impairs the capacity of land to function. Soils are the critical component in land degradation when it involves acidification, contamination, desertification, erosion or salinization.While soil acidification is beneficial in the case of alkaline soils, it degrades land when it lowers crop productivity and increases soil vulnerability to contamination and erosion. Soils are often initially acid because their parent materials were acid and initially low in the basic cations (calcium, magnesium, potassium and sodium). Acidification occurs when these elements are leached from the soil profile by rainfall or the by harvesting of forest or agricultural crops. Soil acidification is accelerated by the use of acid-forming nitrogenous and by the effects of acid precipitation, (Dooley, A. 2006).

3.4.1 Soil contamination

At low levels is often within soil's capacity to treat and assimilate waste material. Soil biota can treat waste by transforming it; soil colloids can adsorb waste material. Many waste treatment processes rely on this treatment capacity. Exceeding treatment capacity can damage soil biota and limit soil function. Derelict soils occur where industrial contamination or other development activity damages the soil to such a degree that the land cannot be used safely or productively. Remediation of derelict soil uses principles of geology, physics, chemistry and biology to degrade, attenuate, isolate or remove soil contaminants to restore soil and values. Techniques include leaching, air sparing, chemical amendments, phytoremediation, bioremediation and natural degradation.

3.4.2 Desertification

is an environmental process of ecosystem degradation in arid and semi-arid regions, often caused by human activity. It is a common misconception that droughts cause desertification. Droughts are common in arid and semiarid lands. Well-managed lands can recover from drought when the rains return. Soil management tools include maintaining soil nutrient and organic matter levels, reduced tillage and increased cover. These practices help to control erosion and maintain productivity during periods when moisture is available. Continued land abuse during droughts, however, increases land degradation. Increased population and livestock pressure on marginal lands accelerates desertification, (Morgan, R. P. C, 1979).

3.4.3 Erosion

Erosion of soil is caused by water, wind, ice, and movement in response to gravity. More than one kind of erosion can occur simultaneously. Erosion is distinguished from weathering, since erosion also transports eroded soil away from its place of origin (soil in transit may be described as sediment). Erosion is an intrinsic natural process, but in many places it is greatly increased by human activity, especially poor land use practices. These include agricultural activities which leave the soil bare during times of heavy rain or strong winds, overgrazing, deforestation, and improper construction activity.

Improved management can limit erosion. Soil conservation techniques which are employed include changes of land use (such as replacing erosion-prone crops with grass or other soil-binding plants), changes to the timing or type of agricultural operations, terrace building, use of erosion-suppressing cover materials (including cover crops and other plants), limiting disturbance during construction, and avoiding construction during erosion-prone periods.

A serious and long-running water erosion problem occurs in China, on the middle reaches of the Yellow River and the upper reaches of the Yangtze River. From the Yellow River, over 1.6 billion tons of sediment flow each year into the ocean. The sediment originates primarily from water erosion (gully erosion) in the Loess Plateau region of northwest China.

Soil piping is a particular form of soil erosion that occurs below the soil surface. It causes levee and dam failure, as well as sink hole formation. Turbulent flow removes soil starting at the mouth of the seep flow and the subsoil erosion advances up-gradient (Jones, 1976). The term sand boil is used to describe the appearance of the discharging end of an active soil pipe (Dooley, 2006).

3.4.4 Salinization

Salinization is the accumulation of free salts to such an extent that it leads to degradation of the agricultural value of soils and vegetation. Consequences include corrosion damage, reduced plant growth, erosion due to loss of plant cover and soil structure, and water quality problems due to sedimentation. Salinization occurs due to a combination of natural and human-caused processes. Arid conditions favour salt accumulation.

This is especially apparent when soil parent material is saline. Irrigation of arid lands is especially problematic (ILRI, 1989). All irrigation water has some level of salinity. Irrigation, especially when it involves leakage from canals and over irrigation in the field, often raises the underlying water table. Rapid salinization occurs when the land surface is within the capillary fringe of saline groundwater. Soil salinity control involves water table control and flushing with higher levels of applied water in combination with tile drainage or another form of subsurface drainage (Drainage Manual, 1993).

3.5 Soil classification

Soil is classified into categories in order to understand relationships between different soils and to determine the usefulness of a soil for a particular use, one . of the first classification system(1880). It was modified a number of times by American and European researchers, and' developed into the system commonly used since late sixties (USDA Soil Taxonomy 1999). It was based on the idea that soils have a particular morphology based on the materials and factors that form them. In the 1960s, a different classification system began to emerge, that focused on soil morphology instead of parental materials and soil-forming factors. Since then it has undergone further modifications. The World Reference Base for Soil Resources (WRB) aims to establish an international reference base for soil classification, (Working Group WRB, 2007).

3.5.1 WRB Soil Taxonomy Categorical level

In 1998, the International Union of Soil Sciences (IUSS) adopted the *World Reference Base for Soil Resources* (WRB) as the Union's system for soil *correlation*. The structure, concepts and definitions of the WRB are strongly influenced by the legend of the FAO-UNISCO 1:5,000,000 Soil Map of the World (FAO, 1974, FAO- UNISCO-ISRIC, 1988; 1990), which in turn borrowed the diagnostic horizons and properties approach from USDA Soil Taxonomy. At the time of its inception, the WRB proposed 30 'Soil Reference Groups' accommodating more than 200 ('second level') Soil Units

3.5.1.1 WRB SOIL Taxonomy- Reference Groups

In the present text, the 30 Reference Soil Groups are aggregated in 10 'sets' Major Soil Groups each allocated to one of the sets on the basis of *'dominant identifiers'*, i.e. those soil forming factor(s) which most clearly conditioned soil formation.

SET #1 holds all soils with more than a defined quantity of *'organic soil materials'*. These organic soils are brought together in only one Reference Soil Group: the HISTOSOLS.

SET #2 contains all *man-made soils*. These soils vary widely in properties and appearance and can occur in any environment but have in common that their properties are strongly affected by human intervention. They are aggregated to only one Reference Soil Group: the ANTHROSOLS.

SET #3 includes mineral soils whose formation is conditioned by the particular properties of their *parent material*. The set includes three Reference Soil Groups:

1. ANDOSOLS of volcanic regions,

2. Sandy ARENOSOLS of desert areas, beach ridges, inland dunes, areas with highly weathered sandstone, etc., and

3. Swelling and shrinking heavy clayey VERTISOLS of back swamps, river basins, lake bottoms, and other areas with a high content of expanding 2:1 lattice clays.

SET #4 accommodates mineral soils whose formation was markedly influenced by their *topographic/physiographic setting*. This set holds soils in low terrain positions associated with recurrent floods and/or prolonged wetness, but also soils in elevated or accidented terrain where soil formation is hindered by low temperatures or erosion.

The set holds four Reference Soil Groups: *In low terrain positions:*

1. Young *alluvial* FLUVISOLS, which show stratification or other evidence of recent sedimentation, and

2. Non-stratified GLEYSOLS in *waterlogged areas* that do not receive regular additions of sediment. In elevated and/or eroding areas:

3. Shallow LEPTOSOLS over hard rock or highly calcareous material, and

4. Deeper REGOSOLS, which occur in unconsolidated materials and which have only surficial profile development, e.g. because of low soil temperatures, prolonged dryness or erosion.

SET #5 holds soils that are only moderately developed on account of their *limited pedogenetic age* or because of *rejuvenation* of the soil material. Moderately developed soils occur in all environments, from sea level to the highlands, from the equator to the boreal regions, and under all kinds of vegetation. They have not more in common than '*signs of beginning soil formation*' so that there is considerable diversity among the soils in this set. Yet, they all belong to only one Reference Soil Group: the CAMBISOLS.

SET #6 accommodates the 'typical' red and yellow soils of *wet tropical and subtropical regions*. High soil temperatures and ample moisture promote rock weathering and rapid decay of soil organic matter. The Reference Soil Groups in this set have in common that a long history of dissolution and transport of weathering products has produced deep and genetically mature soils:

1. PLINTHOSOLS on old weathering surfaces; these soils are marked by the presence of a mixture of clay and quartz (*'plinthite'*) that hardens irreversibly upon exposure to

the open air,

2. deeply weathered FERRALSOLS that have a very *low cation exchange capacity* and are virtually devoid of weatherable minerals,

3. ALISOLS with *high cation exchange capacity* and *much exchangeable aluminium*,

4. Deep NITISOLS in relatively rich parent material and marked by *shiny, nutty structure elements*,

5. Strongly leached, red and yellow ACRISOLS on acid parent rock, with a *clay accumulation horizon, low cation exchange capacity* and *low base saturation*, and

6. LIXISOLS with a *low cation exchange capacity* but *high base saturation percentage*.

SET #7 accommodates Reference Soil Groups in *arid and semi-arid regions*. Redistribution of calcium carbonate and gypsum is an important mechanism of horizon differentiation in soils in the dry zone. Soluble salts may accumulate at some depth or, in areas with shallow groundwater, near the soil surface. The Reference Soil Groups assembled in set #7 are:

1. SOLONCHAKS with a high content of *soluble salts*,
2. SOLONETZ with a high percentage of *adsorbed sodium ions*,
3. GYPSISOLS with a horizon of *secondary gypsum enrichment*,
4. DURISOLS with a layer or nodules of soil material that is *cemented by silica*, and
5. CALCISOLS with *secondary carbonate enrichment*.

SET #8 holds soils that occur in the *steppe zone* between the dry climates and the humid Temperate Zone. This transition zone has a climax vegetation of ephemeral grasses and dry forest; its location corresponds roughly with the transition from a dominance of accumulation processes in soil formation to a dominance of leaching processes. Set #8 includes three Reference Soil Groups:

1. CHERNOZEMS with *deep, very dark surface soils* and *carbonate enrichment* in the subsoil,
2. KASTANOZEMS with less deep, brownish surface soils and carbonate *and/or gypsum accumulation* at some depth (these soils occur in the driest parts of the steppe zone), *and*
3. PHAEOZEMS, the dusky red soils of prairie regions with *high base saturation* but *no visible signs of secondary carbonate accumulation.*

SET #9 holds the brownish and greyish soils of *humid temperate regions*. The soils in this set show evidence of redistribution of clay and/or organic matter. The cool climate and short genetic history of most soils in this zone explain why some soils are still relatively rich in bases despite a dominance of eluviation over enrichment processes. Eluviation and illuviation of metal-humus complexes produce the greyish (bleaching) and brown to black (coating) colours of soils of this set. Set #9 contains five Reference Soil Groups:

1. Acid PODZOLS with a *bleached eluviation horizon* over an *accumulation horizon* of organic matter with aluminium and/or iron,
2. PLANOSOLS with a bleached topsoil over *dense, slowly permeable subsoil*,
3. Base-poor ALBELUVISOLS with a *bleached eluviation horizon tonguing* into a *clay-enriched subsurface horizon*,
4. Base-rich LUVISOLS with a distinct *clay accumulation horizon*, and
5. UMBRISOLS with a thick, *dark, acid surface horizon* that is rich in organic matter.

SET #10 holds the soils of *permafrost regions*. These soils show signs of *'cryoturbation'* (i.e. disturbance by freeze-thaw sequences and ice segregation) such as irregular or broken soil horizons and organic matter in the subsurface soil, often concentrated along the top of the permafrost table. Cryoturbation also results in oriented stones in the soil and sorted and non-sorted patterned ground features at the surface. All 'permafrost soils' are assembled in one Reference Soil Group: the CRYOSOLS.(SOURS FAO,1998).

3.5.2 The USDA soil taxonomy

The Soil Taxonomy developed since the early 1950's are the most comprehensive soil classification system in the world, developed with international cooperation it is sometimes described as the best system so far. However, for use with the soils of the tropics, the system would need continuous improvement.

3.5.3.1 Hierarchy of Categories in the Soil Taxonomy

There are six levels in the hierarchy of categories: Orders (the highest category), suborders, great groups, subgroups, families and series (the lowest category) (USDA, 1978).

1. **Order:** Originating from geographical soil region in the USA diagnostic horizons.
2. **Suborder:** Commonly reflecting temperature and moisture regime or reflecting other diagnostics such as texture and humus.
3. **Great Group:** Other diagnostic horizons.
4. **Subgroup:** Inter- and extra grades.
5. **Family:** Texture class, mineralogy, temperature regime and soil calcareous.
6. **Series:** Place names.

Table 3.3: Brief Descriptions of Soil Orders According to Soil Taxonomy.

SOIL ORDERS	DESCRIPTION
ALFISOLS	Soils with a clayey B horizon and exchangeable cation (Ca + Mg + K + Na) saturation greater than 50% calculated from NH_4OAc-CEC at p^H7.
ULTISOLS	Soils with a clayey B horizon and base saturation less than 50%. They are acidic, leached soils from humid areas of the tropics and subtropics.
OXISOLS	Oxisols are strongly weathered soils but have very little variation in texture with depth. Some strongly weathered, red, deep, porous Oxisols contain large amounts of clay-sized Fe and Al oxides.
VERTISOLS	Dark clay soils containing large amounts of swelling clay minerals (smectite). The soils crack widely during the dry season and become very sticky in the wet season.
MOLLISOLS	Prairie soils formed from colluvial materials with dark surface horizon and base saturation greater than 50%, dominating in exchangeable Ca.
INCEPTISOLS	Young soils with limited profile development. They are mostly formed from colluvial and alluvial materials. Soils derived from volcanic ash are considered a special group of Inceptisols, presently classified under the Andept suborder (also known as Andosols).
ENTISOLS	Soils with little or no horizon development in the profile. They are mostly derived from alluvial materials.
ARIDISOLS	Soils of arid region, such as desert soils. Some are saline.
ANDISOLS	Volcanic soil, which tend to be high in glass content
SPODOSOLS	Soils with a bleached surface layer (A2 horizon) and an alluvial accumulation of sesquioxides and organic matter in the B horizon. These soils are mostly formed under humid conditions and coniferous forest in the temperate region.
GELISOLS	Permafrost soil
HISTOSOLS	Soils rich in organic matter such as peat and muck.

(Source: USDA, 1999)

3.5.4 Land suitability classification

Land suitability is the fitness of a given type of land for a defined use. The land may be considered in its present condition or after improvements. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses (Kevie and Eltom 2004).

3.5.4.1 Structure of the Land Suitability Classification

The framework has the same structure, i.e. recognizes the same categories, in all of the kinds of interpretative classification. Each category retains its basic meaning within the context of the different classifications and as applied to different kinds of land use. Four categories of decreasing generalization are recognized, (FAO, 1976):

- **Orders;** reflecting kinds of suitability (suitable or unsuitable).
- **Classes;** reflecting degrees of suitability within orders .
- **Subclasses;** reflecting kinds of limitations within classes.
- **Units;** reflecting minor differences in production capacity and/ or in management required within subclasses.

3.5.4.1.1 Land Suitability Orders

Two orders are recognized and defined as follows:-

Order S-Suitable Land

Land on which sustained use in the defined manner is expected to yield benefits that will justify the required capital and recurrent inputs.

Order N-Unsuitable Land

Land having characteristics which preclude its sustained use in the defined manner because of an unacceptable level of recurrent or development inputs required.

3.5.4.1.2. Land Suitability Classes

Land suitability classes are subdivisions of the land suitability orders. Three classes are recognized in the suitable order, and two classes in the unsuitable order. Each class groups lands with a similar production capacity within a certain range, expressed qualitatively or quantitatively, for the type of land use under consideration. In certain situations it may be convenient to designate land areas as "conditionally suitable" for a specific use (symbol Sc.). It may be used for relatively small land areas which are not suitable or only marginally suitable for the land use alternative under consideration, but which are highly or moderately suitable under specific conditions. If the land areas for which the specific conditions are relevant, are large , land suitability classifications of the whole study area should be made for a new land use alternative, in which the conditions are specified. Designation of conditionally suitable land will mostly be used only in order to limit the number of land use alternatives that have to be defined, and thus simplify the presentation of the data.

Class S1-Highly Suitable Land

Land which is expected to be highly productive for the defined use and yields high benefits enough justifying the required capital and recurrent inputs. There are no significant limitations that will reduce crop yields or increase recurrent costs for production or conservation.

Class S2-Moderately Suitable Land

Land which is expected to be moderately productive for the defined use and yields moderate benefits sufficiently justify the required capital and recurrent inputs. There are moderately severe limitations likely to reduce crop yields and / or increase recurrent costs for production and conservation.

Class S3-Marginally Suitable Land

Land which is expected to have a low productivity for the defined use and yields benefits that are just high enough justify recurrent costs and capital inputs. There are limitations which in aggregate are sufficiently severe to reduce crop yields and increase recurrent costs for production and conservation.

Class Sc-Conditionally Suitable Land

Land which is expected to be only marginally suitable or unsuitable for the defined use but which would be highly or moderately suitable under very specific conditions of management or for other special uses, which have not been distinguished in the study as a whole. The Unsuitable Order N is subdivided into two classes defined as follow:-

Class N1-Currently Unsuitable Land

Land with very severe limitations which at present cannot be corrected economically and which preclude successful sustained use in the defined manner.

Class N2-Permanently Unsuitable Land

Land with very severe limitations which impeding any possibility of successful use of the land for agricultural production. The definitions are not rigid and should be adapted depending on the defined land use alternative and on whether the classification indicates current or potential suitability, and on whether the classification is quantitative or qualitative. Quantitative definitions (in the Order S) must be in economic, measurable terms, e.g. indicate the ranges of expected net return per feddan.

3.5.4.1.3 Land Suitability Subclasses (and limitations)

Subclasses are subdivisions of the classes reflecting the kinds of the major limitations to profitable land use which determine the class level. It also reflects the general direction of required improvements and so distinguishes lands that differ in the nature of their management requirements. Subclasses within a land suitability class are indicated by one to three lower case letters with mnemonic significance following the class symbol; e.g. subclass S2p, moderately suitable land with physical soil limitations. If there is only one limitation the subclass is indicated by one letter , but if there are two or more limitations the subclass will be indicated by more letters, however, with a maximum of three. In case of more than three limitations then reference should be given to them in the description of the subclass. The sequence of the letters follows the severity of the limitations, the most severe limitation shown first. No subclasses are distinguished within class S1 as land in this class has no significant limitations for the land use under consideration. Also within class N2 no subclasses are distinguished.

3.5.4.1.4 Land Suitability Units

The land suitability units are subdivisions of the subclasses and are used in more detailed studies to distinguish lands with minor differences in production capacity which may or may not be accompanied by different management requirements. The land suitability units may also be used to subdivide lands of class S1 within which no subclasses are recognized. The suitability units are indicated by Arabic numbers between brackets, such as in S2v (1) and S2v (2), which could for instance represent two flat Vertisols areas with moderate physical soil limitations (both in Subclass S2v), but having slight differences in production capacity, yet still within the range set for the class, and having slight differences in management requirements (e.g. fertilizer requirements or cultivation methods).

Table 3. 4: Categories of land suitability classification

Category				
Order		**Class**	**Subclass**	**Unit**
S	Highly suitable	**S1**	S2m	S2e-1*
Suitable	Moderately suitable	**S2**	S2e*	S2e-2*
	Marginally suitable	**S3**	S2me	
N	Conditionally suitable	**N1**	N1m	
Not Suitable	Permanently Not suitable	**N2**	N1e	

3.6.1 Qualitative and Quantitative Classifications

Qualitative classification is one in. which relative suitability is expressed in qualitative terms only, without precise calculation of costs and returns. Qualitative classifications are based mainly on the physical productive potential of the land, with economics only present as a background. They are commonly employed in reconnaissance studies, aimed at a general appraisal of large areas.

Quantitative classification is one in which the distinctions between classes are defined in common numerical terms, which permits objective comparison between classes relating to different kinds of land use. Quantitative classifications normally involve considerable use of economic criteria, i.e. costs and prices, applied both to inputs and production. Specific development projects, including preinvestment studies for these, usually require quantitative evaluation.

Qualitative evaluations allow the intuitive integration of many aspects of benefits, social and environmental as well as economic. This facility is to some extent lost in quantitative evaluations. The latter, however, provide the data on which to base calculations of net benefits, or other economic parameters, from different areas and different kinds of use. Quantitative classifications may become out of date more rapidly than qualitative ones as a result of changes in relative costs and prices (Kivie, 1972).

3.6.2 Classifications of Current and Potential Suitability

A classification of current suitability refers to the suitability for a defined use of land in its present condition, without major improvements. A current suitability classification may refer to the present use of the land, either with existing or improved management practices, or to a different use.

A classification of potential suitability refers to the suitability, for a defined use, of land units in their condition at some future date, after specified major improvements have been completed where necessary. Common examples of potential suitability classifications are found in studies for proposed irrigation schemes. For' a classification to be one of potential suitability it is not necessary that improvements shall be made to all parts of the land; the need for major improvements may vary from one land unit to another and on some land units none may be necessary

3.7 Map Units

A map unit is a collection of areas defined and named the same in terms of their soil components or miscellaneous areas or both. Each map unit differs in some respect from all others in a survey area and is uniquely identified on a soil map. Each individual area on the map is delineation.

Map units consist of one or more components. An individual component of a map unit represents the collection of polypedons or parts of polypedons that are members of the taxon or a kind of miscellaneous area. Parts of polypedons are common when phases are used to divide a taxon.

3.7.1 Kinds of Map Units

Soils differ in size and shape of their areas, in degree of contrast with adjacent soils, and in geographic relationships. Four kinds of map units are used in soil surveys to show the relationships: consociations, *complexes, associations,* and *undifferentiated groups*.

3.7.1.1 Consociations—In a consociation, delineated areas are dominated by a single soil taxon (or miscellaneous area) and similar soils. As a rule, at least one-half of the pedons in each delineation of a soil consociation are of the same soil components that provide the name for the map unit

3.7.1.2 Complexes and associations— Complexes and associations consist of two or more dissimilar components occurring in a regularly repeating pattern. Only the following arbitrary rule related to mapping scale determines whether the name complex or association should be used. The major components of a complex cannot be mapped separately at a scale of about 1:24,000.

3.7.1.3 Undifferentiated groups: Undifferentiated groups consist of two or more taxa components that are not consistently associated geographically and, therefore, do not always occur together in the same map delineation. These taxa are included as the same named map unit because use and management are the same or very similar for common uses. Generally, they are included together because some common feature such as steepness, stoniness, or flooding determines use and management. If two or more very steep soils geographically separated are so similar in their potentials for use and management that defining two or more additional map units would serve no useful purpose, they may be placed in the same unit. Every delineation has at least one of the major components and some may have all of them. The same principles regarding proportion of inclusions apply to undifferentiated groups as to consociations.

3.7.2 Naming Map Units

All map units in a soil survey are named. Different conventions are used for each of the four kinds of map units so that the kind of unit can be determined at a glance. In general, names are as short as is practical; the name of a map unit should be only as long as is necessary to distinguish it from all others in the survey. At times an extra term, not needed to distinguish a phase from all others in the survey, is used so that comparable phases in other areas have the same name.

3.8 Soil Requirement for some Crops

3.8.1Groundnut

Groundnut is grown in a well-drained sandy loam, or sandy clay loam soil. Deep well-drained s oils with a pH of 6. 5 - 7. 0 and high fertility, are ideal for groundnut. Runner and Spanish types are better suited to heavy textured soils than the Virginia types. The loss of pods is usually high in heavier soils. An optimum soil temperature for good germination of groundnut is 30°C. Low temperature at sowing delays germination and increases seed and seedling diseases, (ICRISAT, 1995).

3.8.2 Millet

Millet can be grown in a wide range of soils, but prefers well drained sands or sandy loams. It is better suited to lighter soils, while sorghum occupies heavier and clay soils. In some parts of India, pearl millet is grown in shallow mixed black, red, and lighter colored upland gravelly soils of the Deccan. The crop is less tolerant to water logging and flooding than sorghum. Though grown in poor soils, it often responds well to improved management practices and fertilizer dressings, (Vara, P. V. Prasad and Scott. A. Staggenborg, 2010).

3.8.3 Sesame

Sesame grows best on medium to light well-drained soils that do not stand water. Sesame has been successfully produced on most soil types. Water logged soils inhibit oxygen to the roots and suffocate plants. If the plants do not die, they will become more susceptible to root rots.

Sesame prefers slightly acid to alkaline soils (pH 5-8) with moderate fertility. Although yield potential may be reduced, sesame has shown to grow well in as low as 4.0 pH. Sesame is more sensitive to saline soils than cotton or alfalfa. Beware of years where the water table is low and irrigation well water becomes more concentrated with salts.

Sesame has a deep tap root that grows best in deep non- compacted soils. Maximum yields are achieved when there is no compaction. However, producers have recognized one benefit of sesame’s root is the ability to reduce compaction problems. This generally will require time and energy that may come at a cost to yield. (SESACO, 2012).

3.8.4 *Hibiscuss abdariffa* (Roselle)

Roselle requires a permeable soil, a friable sandy loam with humus being preferable. However, it will adapt to a variety of soils pH of 4.5-8.0, (Singh DP & Mishra CBP, 1987).

CHAPTER FOUR

MATEREALS AND METHODS

4.1 MATEREALS

4.1.1The Farm Area and Extent

El-Fasher Agricultural Research farm cover about 74.1fedan and it's located between latitude 1338' degrees north and between longitudes 2519'degrees west, in North Darfur State, west of El-Fasher city. The main road which connects El-Fasher city to kutum locality runs beside El-Fasher Agricultural Research farm. The study area of the Research farm is situated west of El-Fasher city (Figure 4.1).

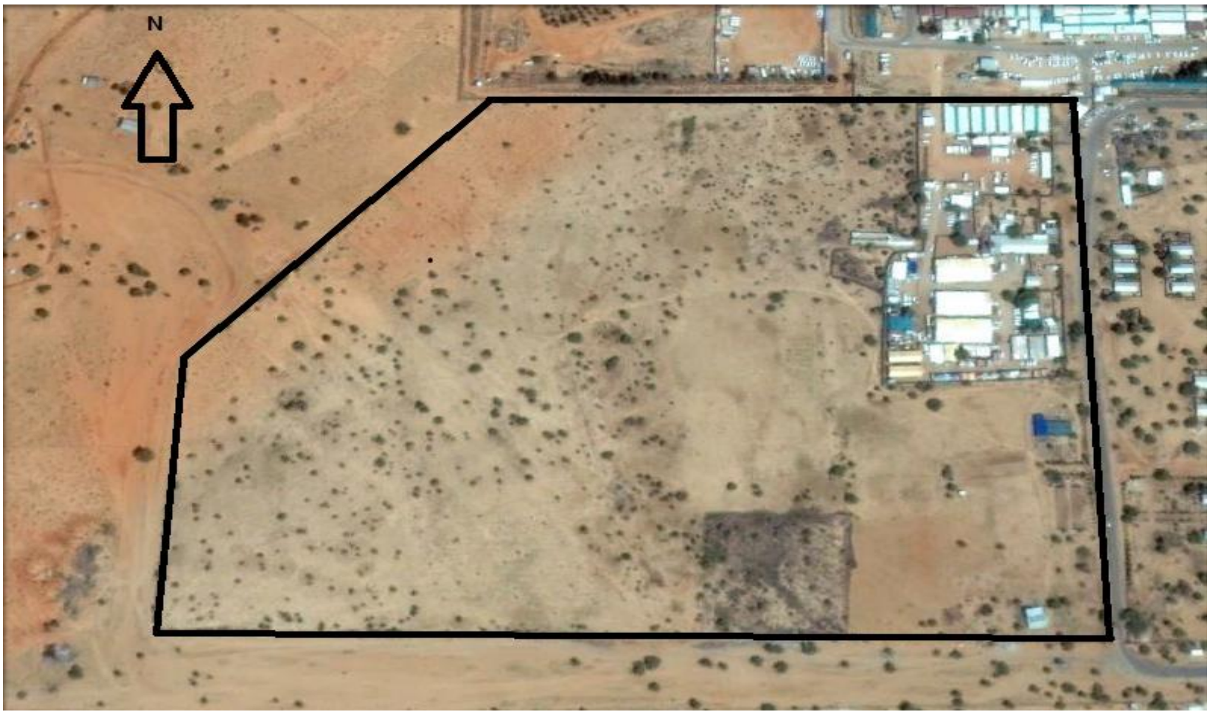


Figure 4. 1: The location of El-Fasher Agricultural Research farm.

4.1.2 Site Information

The dominant climate of the study area Arid type, the summer season starts from middle February and continuous up to June, winter commences from middle of December and continuous up to the second week of February ,the monsoon starts from end of May and continuous up to October .Maximum temperatures of the hottest month (April or May) are 40 –42 C and mean minimum of the coldest month (January) is 8 - 13 C, the average annual rainfall, ranging from 225-400mm, is less than 50 % of the annual potential evapotranspiration in all months, but at least in one month the rainfall is more than 20 percent of the evapotranspiration. The main types of vegetation: in the study area: the Qoz vegetation, Basement vegetation, the Water resources were Surface water and Underground water, Major land use types are Traditional farming (rain fed),Traditional animal breeding.

4.1.3 Field Equipment and tools

- Digger machine (backhoe).
- Auger (bucket).
- GPS (Global Positioning System).
- Digital camera.
- Description sheets, clip boards and markers.
- Measuring tape, nails and shovel and plastic sacks.
- HCL for measuring soil calcareousness.
- Small blunt knife.
- Water bottle.

4.2 METHODS:

4.2.1 Maps and satellite images

Image to Aid field Operation, Google Earth is used as the mapping base in the soil survey area A soil survey is a study of the geography of soil map detail geographic information. Aerial photographs, topographic maps, and other maps are useful refrains whether or not they are used as the mapping base.

4.2.2 Field Survey

The farm site is surveyed in Apr 2015using detailed soil survey with Grid method; this method involved taking of representative soil samples. Augers and open pits were dug to examine the soil morphological characteristics.

4.2.3 Soil sampling methods

Soil samples were taken by two methods which involve either digging profiles and auguring method at the different site in the field. (FAO *et al*, 2001).

4.2.3.2 Auger and pit observation

4.2.3.2.1 Auger observation:

The auger turning and pushing down on the hand bar. The auger boring methods is a way to obtain soil sampling from afferent depths (0-30, 30-60 and 60-100cm) by drilling (auger), without having to dig a pit.

The Auger observation data includes auger number, GPS Coordinates, Landform, topography, slope, surface features, termitaria, trees, shrubs, land use, Water table, Soil drainage class, Samples, Soil type, Depth of cracking. Soil code, Soil horizon (for each: boundary, color and code, mottles, texture coarse fragments, reaction to dilute hydrochloric acid calcium carbonate, Iron-manganese, gypsum, and other features).

4. 2.3.1 Pit observation:

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 sample were collected from the genetic horizons and classified following the soil survey staff USDA (1999). The soil samples were collected and analyzed using standard procedure in laboratory.

4.3 Physical analysis

4.3.1 Mechanical analyses:

Soil particle size was determined using the hydrometer method (Day 1965). Depending on the degree of accuracy of separation required, and the particle sizes of interest, the hydrometer method is well adapted for fast determinations of general categories of sizes present and is used in our analyses.

4.3.2 Saturation Percentage

Saturation percentage (SP) is calculated by dividing the total amount of water added (ml) by the oven-dry weight of the soil (g) used and _multiplying by 100.Soil moisture, as determined on a separate sample, is taken into consideration by adding it to the amount of water used in preparing the saturation paste, (Bashour, L I, 2007).

4.4 Chemical analyses

4.4.1 Soil PH

Is a measure of the activity of ionized H in the soil solution, the pH of a solution is defined as the negative logarithm to the base 10 of the, H ion activity. Soil pH can be measured using a pH meter or by adding a dye to the soil and observing a color change that can be compared with a chart for pH determination. (Michael, E. R, 2009).

4.4.2 Electrical Conductivity (EC)

(Richarcls, L.A, 1954) reported that Soil EC is measured by EC meter.

4.4.3 Organic Carbon

Total carbon was determined by dry combustion in a medium-temperature resistance furnace (Nelson and Sommers, 1982). Organic carbon was calculated as the difference of total carbon and inorganic carbon as quantified in the $CaCO_3$equivalent analyses.

4.4.4 Determination of Nitrogen Kjeidahl

The Kjeldahl method of nitrogen determination involves digestion and distillation. The soil digested in concentrated (H_2SO_4) with catalyst mixture to rise the boiling temperature and to promote the conversion from organic-N to ammonium-N. Ammonium-N from the digest in obtained by steam distillation, using excess NaOH to rise the PH. The distillate is collected in saturated (H_2BO_3) and then titrated with dilute (H_2SO_4) to PH 5.0 (Bremner and Mulvaney,1982).

4.4.5 Cation Exchange Capacity (CEC).

Is a measure of the quantity of readily exchangeable cations neutralizing negative charge in the soil, Ammonium acetate (pH 7.0) has been employed widely for determining soil, (Chapman, H.D, 1965).

4.4.6 Available Phosphorus (Olson)

Determined bysodium bicarbonate extract using spectrophotometer (Olsen, S.R *et al* 1954).

4.4.7 Soluble cations and anions

Calcium and **magnesium** by titration with ethylene di amine tetra acetic acid (Bray 1951).

Sodium and **potassium** determine by flame photometer model C410; **Bicarbonate** by titration with hydrochloric acid (Reitemeier, 1943), Chloride by titration with silver nitrate method (Reitemeier, 1943).

4.4.8 Exchangeable Sodium Percentage, (ESP)

Exchangeable sodium percentage (ESP) is used in the classification of saline and alkali soils or to determine if a sodium hazard exists, this method requires the determination of CEC and exchangeable sodium.

$$ESP = (Exchangeable\ Na\ X\ 100/CEC)$$

4.4.9Sodium Adsorption Ration (SAR)

Sodium adsorption ratio (SAR) is used to estimate or predict ESP by analyzing for soluble Na, Ca, and Mg in soil extract, the soluble and exchangeable cations

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

Na: concentrations are in meq/liter

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Morphological Soil

5.1.1 Surface Soil

Topography flat; site flat land form plain, and Gently undulating (pit 2), Land use (cultivation, research program, Fallow), Drainage class well; Parent material The Aeolian Deposits, absence of cracks, the results of surface description profiles are tabulated in appendix 1.

5.2 Physical Properties

5.2.1 Texture:

The result of mechanical analysis of pit samples is tabulated in (appendix 1). The coarse fraction (2mm)which is formed mainly of sediment .silt +clay content ranged between the extreme values 37%(pit 5= 105 - 162) and 14%(pit 4 =0 – 30). The general trend for (silt+clay) is decrease with depth. No regularity in this trend is found in all profile, and no consistent relation between layers. The texture in certain profile constant with depth whilst an increase in (silt+clay) content with depth is observed in some profile. Sand ranged between the extreme values of 86%(pit 2=0-30) and 63% (pit 5=105-162), sand decrease with depth in some profile. the main textural class in the all farm profiles are loamy sand result in(appendix 1),.

5.2.2 Color

The color is one of the Maine soil properties which recognizing soil horizon her use soil Munsel color book to determine the wet color of soil by comparing the soil to individual color chaps. Color ranging from yellowish brownm, orgreash brown to dark yellowish brown, or red grech brown in topsoil. The color of the subsoil is either yellowish brown, to grayish brown, this reflect to the higher percentage of sand, and the lowest range of organic matter, result in(appendix 1).

5.2.3 Structure

The structure is very weekly topsoil week developed single grien, and subsoil ranged from medium developed single green to medium developed massive .but there are some correlation between structure and texture, result in(appendix 1).

Table 5.1: Soil physical Properties

Pit No	Soil depth	Structure	Color	Texture
1	topsoil	Single grain	yellowish brown	Loamy sand
	Sub soil	massive	Bright Broun	Loamy sand
2	topsoil	Single grain	BrightReddish Broun	Loamy sand
	Sub soil	massive	Bright Reddish Broun	Loamy sand
3	topsoil	Single grain	yellowish brown	Loamy sand
	Sub soil	massive	Brown	Loamy sand
4	topsoil	Single grain	BrightReddish Broun	Loamy sand
	Sub soil	massive	BrightReddish Broun	Loamy sand
5	topsoil	Single grain	BrightReddish Broun	Loamy sand
	Sub soil	massive	BrightReddish Broun	Loamy sand

5.3 Chemical Properties

5.3.1 Soil pH

pH determination ware made on samples. The reaction of the soil is alkaline, ranged from 7.2 - 8.0 in topsoil to 7.5 - 7.9 in sup soil. Variation throughout the profile is quite significant and PH tends to rise with depth, result in (appendix 1)

5.3.2 Saturation Extracts

The saturation extracts obtained from the samples were analyzed for the estimation of salinity and determination of soluble salts composition. The results of analysis are shown in (appendix 1).

5.3.3 Salinity

This property was determined in the entire disturbed pit and auger sample, being measured as the electrical connectivity of the saturation extract in ds/m. at 25 Centigrade degree. Percent salt is calculated from the electrical conductivity. In the most of the pits percent salt concentration similar. There appear thus to be a define leaching process by rainfall. The electrical conductivity of the saturation extract ranged between 0.3 - 0.4ds/m. for topsoil to0.3 - 0.4ds/m. for subsoil. According to the approximate limit of salinity classes, the soils of the area are belonging to class 0. The general pattern is non-saline or free soil.

5.3.4 Composition of Soluble Salts

Seventeen analyses were made to determine the ionic composition and concentration of soluble salt in the saturation extract each showed a range of values as can be seen from (appendix 1). Only four cations and two anions are investigated.
Among the anions determined chloride and bicarbonate are equally important.

5.3.5 Cation Exchange Capacity (CEC)

Cation exchange capacity was determined and the result are shown appendix i. values of cation exchange capacity(CEC) ranged from 6 -8 cmol (+) kg-1 in topsoil to 6 - 9 cmol(+) kg-1in subsoil.

5.3.6 Soluble Sodium

The results as tabulated in (appendix 1) indicate the range is low between 2.1 – 3.6 topsoil to 2.2 – 3.3 subsoil.

5.3.7 Exchangeable Sodium

Exchangeable sodium was determined due to the influence of this property of the permeability of soil to water and hence on soil fertility. The result expressed in (appendix 1), show general tendency for exchangeable sodium to increase markedly with depth. The values are relatively ranging from 1.1 to 1.2 cmol(+) kg-1.

5.3.8 Exchangeable Sodium Percentage (ESP)

This property was determined for estimation of the alkali status of the soil. The results are shown in (appendix 1), they show a remarkable increase with depth. The Exchangeable Sodium Percentage (ESP) ranging from 12 – 17topsoil to13 – 20subsoil. According to the standards of the US soil survey manual, the farm area is non sodic soil.

5.3.9 Sodium Adsorption Ratio (SAR)

This property has been determined for all samples. The results are shown in (appendix 1), thy show a positive correlation with exchangeable sodium percentage values, the highest sodium adsorption ratios are obtained in soil sample at pit 5.

5.3.10 Exchangeable Potassium

The results for exchangeable potassium are tabulated in (appendix 1), the values are relatively high rating from 0.8 – 1.0 cmol(+) kg-1 soil. Exchangeable potassium due to the influence of property on the permeability of soil to water and hence on soil fertility. Potassium (K) effects often similar to sodium (Na) depended soil type spatially texture.

5.3.11 Calcium Carbonate

The result for calcium carbonate in the soil of agricultural research farm has low content. Average between 0.1% topsoil to0.4% subsoil, analysis are shown in (appendix 1).

Table 5.2: Soil Chemical analysis of Soil Profiles

Soil property		Depth cm	
		Topsoil (0 – 30)	**Subsoil (30 - 60)**
Silt+Clay%	Average	16	17
pH paste	Average	7.6	7.7
CEC cmol(+) kg-1	Average	7	7
Ex. Na, cmol(+) kg-1	Average	1.1	1.2
, cmol(+) kg-1 Ex. K	Average	0.8	0.8
Ex. Ca+Mg, cmol(+) kg-1	Average	5.1	5.5
Total N %	Average	0.02	0.02
Org.C %	Average	0.04	0.05
C:N	Average	1.6	2.1
CaCO3 %	Average	0.1	0.4
Avail. P ppm	Average	3.0	3.0
EC ds/m	Average	0.3	0.3
ESP	Average	14	16
(meq/l)Na	Average	2.8	2.7

5.3.12 Fertility Status

Rating of fertility status that shown in (table 5.3) are Organic carbon, Nitrogen, Phosphorus, has been analyses in the top soil, and Potassium, pH, Cation Exchangeable Capacity (CEC), and Base saturation percentage In all horizon which were taken Rating 1 Adequate is pH, Rating 2 low are potassium, CEC, Organic matter, and Base saturation percentage, and Rating 3 is Deficient of Organic carbon, phosphorus, and nitrogen. The fertility status is classified in order suitable, class tow with subclass limitation of fertility and unit of minor management which expressed S2f

Table 5.3: Fertility rating

Soil parameter	**Range**	**Rating**	**Degree**
Ph(paste)	7.2 - 8.0	1	Adequate
O.C %	0.01-0.08	3	Deficient
O.M %	0.05 – 0.14	3	Deficient
N %	0.01-0.03	3	Low
Available P ppm	2.0 - 4.0	2	Low
CEC **cmol(+) kg-1**	6 – 9	2	Low
K **cmol(+) kg-1**	0.7 - 0.9	2	Low

5.4 Soil Classification and Correlation

The soil of agricultural research farm – El-Fasher were classified according to the Soil Taxonomy of the United State Department of Agriculture (USDA, 1999).and correlated with the FAO/UNESCO, 1998 (Table). At regional level the soil were classified to the subgroup level and lately correlated with the existing soil family.

Table 5.4: Soil Classification of the study area

USDA Soil Taxonomy(1999)	Order	Entisols
	Sub order	Psamments
	Grete group	Quartzipsamments
	Sub group	Typic Quartzipsamments,
	family	Typic Quartzipsamments, loamy sand, isohyperthermic
	Series	El-Fasher(propose)
FAO / UNICCO 1998	Unit(group)	Arenosol
	Subunit	Quartzipsamments

5.5 Mapping units

Depending on the purpose of detailed soil survey, and land characteristics determined. That included topography, texture, drainage, reaction, and salinity. Soil can then be groped in delineations (map units) according to similarities and differences of characteristic.

Soil Map of ARC Farm - Elfasher

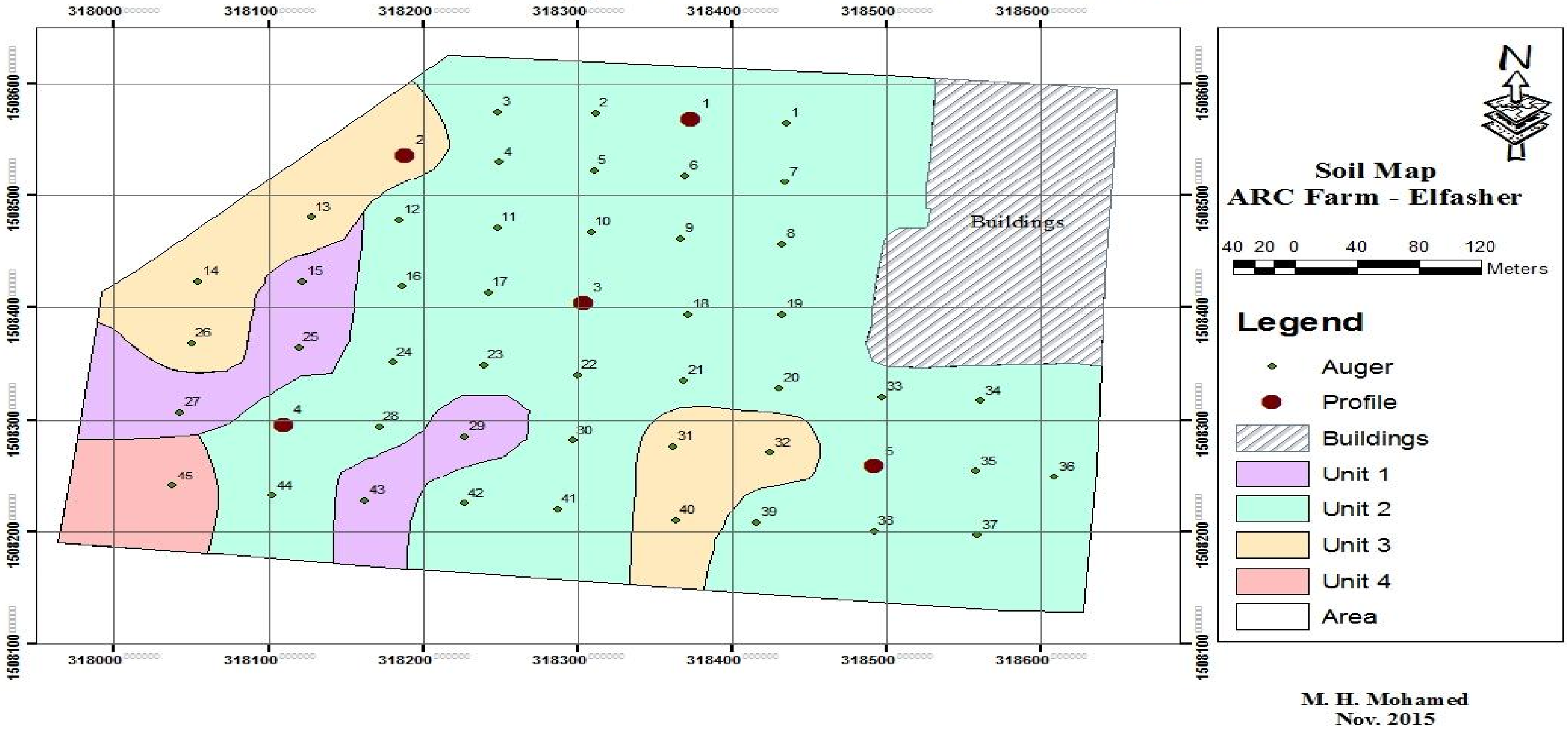


Table 5.5: Main Characteristics of Soil Map Unit of ARC Farm _ El-Fasher

Map Unit	**Symbol**	**Name**	**Main Characteristics of Soil**	**Constraints**	**Extend Feddans**
1	**SL**	Sand light	Dominantly loamy sand soil with subsoil containing > 20% silt+clay, pH 7.6 to 6.4,	fertility	5.7
2	**SH**	Sand heavy	Dominantly loamy sand soil with topsoil containing > 20% silt+clay, pH 8.0 to 7.8	fertility	50.5
3	**SD**	Sand dune	Dominantly loamy sand soil with < 20 % silt+claythrough out profile, pH 7.7 to 7.5, undulating topography	Fertility, texture, topography.	7.9
4	**SP**	Sand plain	Dominantly loamy sand soil with > 20 % silt+claythrough out profile, pH less than 7.0	fertility	2.3
Building					7.9
Total					74.1

5.6 Land Suitability Classification

Land suitability evaluation is the process of assessing the suitability of land for specific kind of use. These maybe major kinds of land use. Such as irrigated agriculture, livestock production, etc. the land suitability for crop production of this area was done according to the framework for land Evolution (FAO 1967). Four classes are identified (table5.7). Which are: 1-Moderately suitable (S2) the searcher find during this study the soil of units (1, 2, 4) or units (**SL, SH**, **SP**), are considering moderately productive for the defines use and yields moderate benefits in (), because it has limitation which ware fertility, physical properties. Which were taken the units S2fp (table5.7). 2-margenaly suitable (S3). This class consider marginally productive for the defined use and yields marginally benefits in unit (4) or unit (**SD**). Because it has limitation which are fertility, texture, topography, and physical properties, which are taken unit S3fp. The evaluation of this study area for the production of some crop adapted to the area (table5.7).

Table 5. 6: Land suitability Characteristics

Map Unit	Symbol	Soil Profile or Auger	Soil Characteristics (Topsoil, Subsoil)			Limitation
			Texture(silt + clay)	pH	ECe	
1	**SL**	28	LS 20/17	7.6/6.4	0.1	Fertility
2	**SH**	20	LS 18/20	8.0/7.8	0.1	Fertility
3	**SD**	5	LS 18/18	7.7/7.5	0.3/0.2	Fertility, Texture
4	**SP**	50	LS 20/22	6.7/6.4	0.3/0.2	Fertility

Table 5. 7: Soil Characteristic Rating for land suitability Classification

Map Unit	Symbol	Soil Characteristic Rating			Rating	Limitation
		Texture(silt + clay)	pH	ECe		
1	**SL**	**1**	1	1	**1**	Fertility, physical properties
2	**SH**	**1**	1	1	**1**	Fertility, physical properties
3	**SD**	**2**	1	1	**2**	Fertility, texture, Physical properties, topography
4	**SP**	**1**	1	1	**1**	Fertility, physical properties

Table 5. 8: Soil Suitability Classification of the ARC Farm

Map Unit	Symbol	Order	Class	Subclass	Unit
1	**SL**	Suitable	S2 Moderately Suitable	S2f Fertility, physical properties	S2f-1
2	**SH**	Suitable	S2 Moderately Suitable	S2f Fertility, physical properties	S2-1
3	**SD**	Suitable	S3 Marginally Suitable	S3fp Fertility, physical properties, texture, topography.	S3fp-2
4	**SP**	Suitable	S2 Moderately Suitable	S2f Fertility, physical properties	S2f-1

5.7 land Suitability Unit in the study area

The soil of the study area was classified to land suitability units (table) as follows:

Unit (1, 2, 4) or (SL, SH, SP) - Moderately suitable soil. (S2)

This class considering moderately productive for the defined use and yield moderately benefits, because it has tow limitation which were physical factor, fertility and texture which were taken the unit S2f in soil map unit (1, 2, 4) or (**SL, SH**, **SP**) , for this case there are moderate saver limitation likely to reduce crop yields and increase recurrent cost for production and conservation.

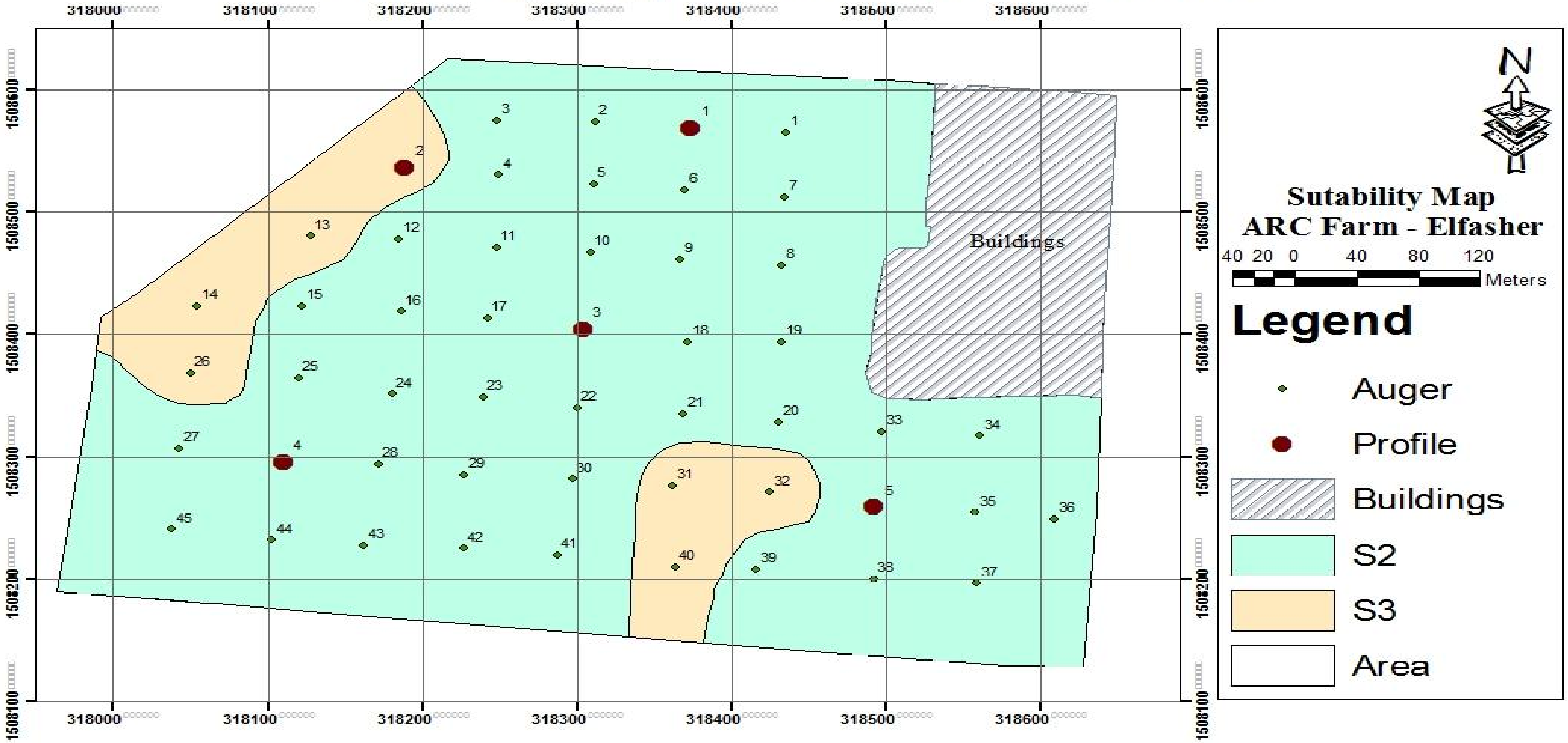
Unit (3) or (SD) - Marginally suitable soil. (S3)

This class considering marginally productive for the deferent use and yield marginally benefits, because it has three limitation which were physical factor, fertility, texture , and topography which were taken the unit S3fpt in soil map unit(3) or(**SD**), for this case there are marginally serve limitation to reduce crop yields and increase recurrent costs for production and conservation.

Table 5. 9: Crop suitability classes for some crops in the ARC Farm.

MAP UNITS		FIELD CROPS				VEGETABLES	HASHAB	GRAZING	Total Area Feddans
Symbol	**NAME**	**Dukhn**	**ground-nuts**	**Sesame**	**Karkad**	**cucumber, water- melon**	**cultivation(Acacia senegal**	**(Range-lands)**	
SL	Sand light	S2f,	S2f	S2f	S2f	S2f	S2f	S2f	5.7
SH	Sand heavy	S2f,	S2f,	S2f	S2f	S2f	S2f	S2f	50.5
SD	Sand dune	S3f,t	S3f,t	S3f,t	S3f,t	S3f,t	S3f,t	S3f,t	7.9
SP	Sand plain	S2f,t	S2f,t	S2f	S2f	S2f S2f	S2f	S2f	2.3

Sutability Map of ARC Farm - Elfasher



M. H. Mohamed
Nov. 2015

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

1. The soil chemical analyses reflect minor differences in the soils of the farm and this is due to the inherent properties from the parent materials (quartzitic mineralogy). Their low cation exchange capacity has affected their chemical properties particularly under the present arid conditions.
2. The soil texture properties and related characteristics were found to have some variations particularly in relation to particle size classes. slightly loamy sand
3. The farm land was classified as moderately and marginally suitable with fertility and topography limitations. The fertility limitation was due to sandy nature of most of the soils, but topography limitation is confine to the undulating parts of the farm.

6.2 RECOMMENDATIONS

1. Additional of organic matter which leads to building and minting health soils which will have great positive influence on plant.
2. Applying a good system of irrigation method with good quality water in appropriate time to avoid soil filtration.
3. Conducting experiments crops suitable for the climate and soil of El Fasher agricultural Research Farm.
4. Experiments and research recommendations on the soil of El Fasher agricultural Research farm applied in soils similar to Farm.
5. Good farming system and operations such as fallow and ridding should be practiced to allow the soil nutrient replenishment, these measures are very important to avoid soil degradation and nutrient loss.

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APPENDICES

Appendix 1
Profile descriptions
And
Laboratory data (profiles)

Information on the site:

Profile No.: 01

Classification: Typic Quartzipsamments, loamy sand, isohyperthermic

Date of examination: April 2015

Authors of description slah khodra

Location : N 13°38’25.11" E 25°19’15.50"

El-Fasher agricultural research farm North Darfur.

Landform: Physiographic position: flat site

Landform of surrounding country: Plain

Vegetation scattered Accacia

Land use: cultivation Sesame

Climate: Arid.

General information on the soils:

Parent material: aeolian sand deposits

Permeability of subsoil: well drainage

Moisture conditions in the soil: dry almost

Depth of ground water: Very deep not affected the profile

Presence of surface stones: Nil

Evidence of erosion: Nil

Human influence cultivation (Traditional Rain fed)

Depth		Description
0-35	cm	Yellowish Brown (10YR 5/8)dry; Brown (10YR 4/6) moist; loamy sand; weak fine and single grain ; non sticky; non plastic, friable moist, slightly hard dry ; very few fine roots; non calcareous; clear wavy boundary; pH 7.2
35-74	cm	Bright Brown 7.5YR 5/8)dry; Brown (7.5YR 4/6) moist; loamy sand; weak fine and massive structure; slightly hard, friable moist, slightly sticky; slightly plastic; very few fine roots; few fine pores; gradual smooth boundary; pH 7.9
74-102	cm	Bright Brown 7.5 YR 5/8) dry; Brown (7.5YR 4/6) moist; loamy sand; massive; hard dry, friable moist, slightly sticky and slightly plastic ; non calcareous; clear smooth boundary; pH 7.9
102-154	cm	Dull Yellowish Orange (10YR 7/2) dry; Dull Yellowish Brown (10YR 4/3) moist; loamy sand; massive; slightly hard dry, friable moist, slightly sticky and slightly plastic; non calcareous; clear smooth boundary; pH 8.0.
154-210	cm	Dull Yellowish Broun (10YR 4/3) dry; Dull Yellow Orange (10YR 6/3) moist; loamy sand; single grain; slightly hard dry, friable moist, slightly sticky and slightly plastic; non calcareous; clear smooth boundary; pH 7.6.

Pit No.	Lab. No.	Depth Cm	Sand %	Silt %	Clay %	pH paste	ECe dS/m	Exchangeable cations, cmol(+) kg-1			CEC cmol(+) kg-1	O.M %	O.C %	Total N%
								Ca+Mg	K	Na				
1	**1**	**0-35**	**84**	**14**	**2**	**7.2**	**0.4**	**4.8**	**1.0**	**1.2**	**7**	**0.12**	**0.07**	**0.03**
	2	**35-74**	**82**	**16**	**2**	**7.9**	**0.4**	**6.9**	**0.9**	**1.2**	**9**	**-**	**-**	**0.03**
	3	**74-102**	**78**	**18**	**4**	**7.9**	**0.2**	**14.9**	**0.9**	**1.2**	**17**			
	4	**102-154**	**76**	**20**	**4**	**8.0**	**0.5**	**11.2**	**0.8**	**1.0**	**13**			
	5	**154-210**	**86**	**14**	**0**	**7.6**	**0.3**	**4.2**	**0.8**	**1.0**	**6**			

Pit No.	Depth Cm	C:N %	CaCO3 %	Olsen P PPm	ESP	SAR	Soluble cations (meq/l)				Soluble cations (meq/l)				
							Ca+Mg	K	Na	sum	CO3	HCO3	Cl	SO4	sum
1	**0-35**	**2.3**	**-**	**3**	**17**	**4**	**1.7**	**1.2**	**3.6**			**0.25**	**1.9**		
	35-74	**-**	**0.7**	**2**	**13**	**3**	**1.7**	**1.0**	**3.3**			**0.25**	**1.8**		
	74-102		**0.2**		**7**	**3**	**1.5**	**0.9**	**2.2**			**0.18**	**1.5**		
	102-154		**0.2**		**7**	**4**	**1.4**	**0.9**	**3.0**			**0.18**	**1.1**		
	154-210		**0.3**		**16**	**4**	**1.2**	**0.8**	**3.0**			**0.25**	**1.2**		

Information on the site:

Profile No.: 02

Classification: Typic Quartzipsamments, loamy sand, isohyperthermic

Date of examination: April 2015

Authors of description Mahmoud Hashim

Location: E 13°38'23.97" N 25°19'9.18"

El-Fasher agricultural research farm North Darfur.

Elevation: 744m

Landform:

Physiographic position: flat site

Landform of surrounding country: Plain

Vegetation scattered Accacia

Land use: Fallow

Climate: Ared.

General information on the soils:

Parent material: aeolian sand deposits

Permeability of subsoil: well drainge

Moisture conditions in the soil: dry almost

Depth of ground water : Very deep not affected the profile

Presence of surface stones: Nil

Evidence of erosion: Nil

Human influence: cultivation(Traditional Rainfed)

Depth		Description
0 –35	cm	Bright Reddish Brown (5YR 5/8)dry; Dull Reddish Brown (5YR 4/8) moist; loamy sand; weak fine and single grain ; non sticky; non plastic, friable moist, slightly hard dry ; very few fine roots; non calcareous; clear wavy boundary; pH 7.7
35 _ 96	cm	Bright Reddish Brown (5YR 5/8)dry; Dull Reddish Broun (5YR 4/8) moist moist; loamy sand; weak fine and massive structure; hard, friable moist, slightly sticky; slightly plastic; very few fine roots; few fine pores; gradual smooth boundary; pH less than 7.5
96 _ 200	cm	Orang (7.5YR 6/8) dry; Bright Brown (7.5YR 5/6) moist; loamy sand; massive; hard dry, friable moist, slightly sticky and slightly plastic; very few very fine roots; very few fine pores; non calcareous; gradual smooth boundary; pH 7.7

Pit No	Lab. No	Depth Cm	Sand %	Silt %	Clay %	pH paste	ECe dS/m	Exchangeable cations, cmol(+) kg-1				CEC cmol(+) kg-1	O.M %	OC %	Tota N %
								Ca+Mg	K	Na	sum				
2	1	0-35	86	14	-	7.7	0.3	6.2	0.8	1.0		8	-	-	0.03
	2	35-96	86	14	-	7.5	0.2	4	0.8	1.2		6	0.051	0.03	0.02
	3	96-200	86	14	-	7.7	0.2	4	0.8	1.2		6			

Pit NO	Depth Cm	C:N	CaCO3 %	Olsen P PPm	ESP	SAR	Soluble cations (meq/l)				Soluble anions (meq/l)				
							Ca+Mg	K	Na	sum	CO3	HCO3	Cl	SO4	sum
2	0-35	-	0.1	2	12	2	1.5	1.0	2.3			0.18	1.2		
	35-96	1.5	0.2	2	20	3	1.2	0.9	2.3			0.18	1.2		
	96-200		0.3		20	3	1.2	0.9	2.1			0.20	1.2		

Informatiom on the site:

Profile No.: 03

Classification: Typic Quartzipsamments, loamy sand, isohyperthermic

Date of examination: April 2015

Authors of description slah khodra

Location : N 13°38'19.48" E 25°19'13.03"

El-fasher agricultural research farm North Darfur.

Elevation: 739m

Landform: Physiographic position: flat site
Landform of surrounding country: Plain

Vegetation scattered Accacia

Land use: cultivation Sesame

Climate: Arid.

General information on the soils:

Parent material: aeolian sand deposits

Permeability of subsoil: well drainage

Moisture conditions in the soil: dry almost

Depth of ground water: Very deep not affected the profile

Presence of surface stones: Nil

Evidence of erosion: Nil

Human influence cultivation (Traditional Rain fed)

Depth		**Description**
0-22	cm	Yellowish Brown (10YR 5/8)dry; Brown(10YR 4/6) moist; loamy sand; weak fine and single grain ; non sticky; non plastic, friable moist, slightly hard dry ; very few fine roots; non calcareous; clear wavy boundary; pH 7.8
22-49	cm	Brown (10YR 4/6)dry; Dull Yellowish Brown (10YR 4/3) moist; loamy sand; weak fine and massive structure; slightly hard, friable moist, slightly sticky; slightly plastic; very few fine roots; few fine pores; gradual smooth boundary; pH less than 7.8
49-100	cm	Brown (10YR 4/6) dry; Dull Yellowish Brown (10YR 4/3) moist; loamy sand; massive; hard dry, friable moist, slightly sticky and slightly plastic; non calcareous; gradual smooth boundary; pH 8.0.
100- 150	cm	Brown (10YR 4/6) dry; Dull Yellowish Brown(10YR 4/3) moist; loamy sand; massive; slightly hard dry, friable moist, slightly sticky and slightly plastic; non calcareous; gradual smooth boundary; pH 7.8.
150- 210	cm	Dull Yellowish Brown (10YR 4/3) dry; Dark brown (10YR 3/3) moist; loamy sand; massive; hard dry, friable moist, slightly sticky and slightly plastic; non calcareous; gradual smooth boundary; pH 7.9.

Pit No.	Lab. Cm	Depth %	Sand %	Silt %	Clay %	pH paste	ECe dS/m	Exchangeablecations, cmol(+) kg-1			CEC cmol(+) kg-1	O. M %	OC %	Total N %
								Ca+Mg	K	Na				
3	**1**	**0-22**	**84**	**14**	**2**	**7.8**	**0.3**	**4.8**	**1.0**	**1.2**	**7**	**-**	**-**	**0.02**
	2	**22-49**	**85**	**13**	**2**	**7.8**	**0.2**	**6.9**	**0.9**	**1.2**	**6**	**-**	**-**	**0.01**
	3	**49-100**	**82**	**14**	**4**	**8.0**	**0.2**	**14.9**	**0.9**	**1.2**	**9**			
	4	**100-150**	**79**	**17**	**4**	**7.8**	**0.2**	**11.2**	**0.8**	**1.0**	**10**			
	5	**150-210**	**80**	**14**	**6**	**7.9**	**0.3**	**4.2**	**0.8**	**1.0**	**12**			

Pit No.	Depth Cm	C:N	CaCO3 %	Olsen P PPm	ESP	SAR	Soluble cations (meq/l)				Soluble anions (meq/l)				
							Ca+Mg	K	Na	sum	CO3	HCO3	Cl	SO4	sum
3	**0-22**	**-**	**0.1**	**2**	**14**	**3**	**1.4**	**1.2**	**2.1**			**0.13**	**1.4**		
	22-49	**-**	**0.6**	**2**	**`18**	**3**	**1.3**	**1.9**	**2.1**			**0.22**	**1.6**		
	49-100		**0.4**		**15**	**3**	**1.1**	**1.0**	**2.2**			**0.19**	**1.5**		
	100-150		**1.0**		**14**	**3**	**1.1**	**0.7**	**2.2**			**0.20**	**1.5**		
	150-210		**-**		**11**	**4**	**1.1**	**0.9**	**2.6**			**0.20**	**1.7**		

Informatiom on the site:

Profile No.: 04

Classification: Typic Quartzipsamments, loamy sand, isohyperthermic

Date of examination: April 2015

Authors of description mhamoud hashim

Location : N 13°38'15.9" E 25°19'66.4"

El-fasher agricultural research farm North Darfur.

Elevation: 740m

Landform: Physiographic position: flat site

Lanform of surrounding country: Plain

Vegetation scattered Accacia

Landuse: cultivation Sesame

Climate: Arid.

General information on the soils:

Parent material: aeolian sand deposits

Permeability of subsoil: well drainage

Moisture conditions in the soil: dry almost

Depth of ground water: Very deep not affected the profile

Presence of surface stones: Nil

Evidence of erosion: Nil

Human influence cultivation (Traditional Rainfed)

Depth		Description
0-35	cm	Bright Reddish Brown (10YR 5/8)dry; Brown(10YR 4/6) moist; loamy sand; weak fine and single grain ; non sticky; non plastic, friable moist, slightly hard dry ; very few fine roots; non calcareous; clear wavy boundary; pH 7.9
35-57	cm	Bright Reddish Broun (10YR 5/8)dry; Brown (10YR 4/6) moist; loamy sand; weak fine and massive structure; slightly hard, friable moist, slightly sticky; slightly plastic; very few fine roots; few fine pores; gradual smooth boundary; pH less than 7.8
57-102	cm	Bright Reddish Brown (10YR 5/8) dry; Brown (10YR 4/6) moist; loamy sand; massive; slightly hard dry, friable moist, slightly sticky and slightly plastic; non calcareous; gradual smooth boundary; pH 8.0.
102-150	cm	Grayish Yellow Brown(10YR 6/2)dry; Yellowish Brown (10YR 5/8) moist; loamy sand; massive; hard dry, friable moist, slightly sticky and slightly plastic ; non calcareous; clear smooth boundary; pH 7.9.
150-210	cm	Dull Yellow Orange(10YR 7/3) dry; Dull Yellow Orange (10YR 6/4) moist; loamy sand; massive; slightly hard dry, friable moist, slightly sticky and slightly plastic; non calcareous; clear smooth boundary; pH 7.9

Pit No.	Lab. No.	Depth Cm	Sand %	Silt %	Clay %	pH paste	ECe dS/m	Exchangeable cations, cmol(+) kg-1				CEC cmol(+) kg-1	O.M %	OC %	Total N %
								Ca+Mg	K	Na	sum				
4	**1**	**0-35**	**86**	**12**	**2**	**7.9**	**0.3**	**4.1**	**0.9**	**1.0**		**6**	**0.02**	**0.01**	**0.02**
	2	**35-57**	**84**	**14**	**2**	**7.8**	**0.3**	**4.1**	**0.9**	**1.0**		**6**	**0.14**	**0.08**	**0.03**
	3	**57-102**	**84**	**14**	**2**	**7.8**	**0.2**	**5.1**	**0.9**	**1.0**		**7**			
	4	**102-150**	**82**	**14**	**4**	**7.9**	**0.3**	**7.8**	**0.8**	**1.4**		**0**			
	5	**150-210**	**84**	**12**	**2**	**7.9**	**0.3**	**2.8**	**09**	**1.3**		**5**			

Pit No.	Depth Cm	C:N	CaCO3 %	Olsen P PPm	ESP	SAR	Soluble cations (meq/l)				Soluble anions (meq/l)				
							Ca+Mg	K	Na	sum	CO3	HCO3	Cl	SO4	sum
4	**0-35**	**0.5**	**0.1**	**3**	**16**	**3**	**1.5**	**1.2**	**2.2**			**0.25**	**1.2**		
	35-57	2.6	**0.2**	**3**	**16**	**3**	**1.5**	**1.0**	**2.2**			**0.18**	**1.2**		
	57-102		**-**		**14**	**3**	**1.3**	**0.9**	**2.1**			**0.18**	**1.4**		
	102-150		**-**		**14**	**3**	**1.2**	**1.2**	**2.2**			**0.20**	**1.6**		
	150-210		**0.3**		**26**	**2**	**1.3**	**0.9**	**1.3**			**0.18**	**0.5**		

Informatiom on the site:

Profile No.: 05
Classification: Typic Quartzipsamments, loamy sand, isohyperthermic
Date of examination: April 2015
Authors of description slah khodra
Location: N 13°38'14.77" E 25°19'19.38"

El-Fasher agricultural research farm North Darfur.

Elevation: 738m

Landform: Physiographic position: flat site Lanform of surrounding country: Plain

Vegetation scattered Accacia

Landuse: cultivation Sesame
Climate: Arid.
General information on the soils:
Parent material: aeolian sand deposits
Permeability of subsoil: well drainage
Moisture conditions in the soil: dry almost
Depth of ground water: Very deep not affected the profile
Presence of surface stones: Nil
Evidence of erosion: Nil
Human influence cultivation (Traditional Rainfed)

Depth		Description
0-38	cm	Bright Reddish Broun (10YR 5/8)dry; Brown (10YR 4/6) moist; loamy sand; weak fine and single grain ; non sticky; non plastic, very friable moist, slightly hard dry ; very few fine roots; non calcareous; few fine pores; clear wavy boundary; pH 8.0
38-67	cm	Bright Reddish Broun (10YR 5/8)dry; Brown (10YR 4/6) moist; loamy sand; weak fine and massive structure; slightly hard, friable moist, slightly sticky; slightly plastic; very few fine roots; gradual smooth boundary; pH less than 7.8
67-105	cm	Bright Reddish Broun (10YR 5/8) Brown (10YR 4/6) dry; (10YR 3/3) moist; loamy sand; massive; hard dry, friable moist, slightly sticky and slightly plastic; non calcareous; clear smooth boundary; pH 8.0.
105-162	cm	Dull Yellowish Brown (10YR 5/4) dry; Dull Yellowish Brown (10YR 4/3) moist; loamy sand; massive; hard dry, friable moist, slightly sticky and slightly plastic ; non calcareous; clear smooth boundary; pH 8.0.
162-220	cm	Dull Yellowish Brown (10YR 5/4) dry; Dull Yellowish Brown (10YR 4/3) moist; loamy sand; massive; hard dry, friable moist, slightly sticky and slightly plastic; non calcareous; clear smooth boundary; pH 8.3
220-240	cm	Dull Yellow Orange (10YR 7/2) dry; Grayish Yellow Brown (10YR 6/2) moist; loamy sand; single grain; non calcareous; clear smooth boundary; pH 8.3.

Pit No.	Lab. No.	Depth Cm	Sand %	Silt %	Clay %	pH paste	ECe dS/m	Exchangeable cations, cmol(+) kg-1				CEC cmol(+) kg-1	O.M %	O.C %	Total N %
								Ca+Mg	K	Na	sum				
5	1	0-38	82	16	2	8.0	0.3	5.2	0.7	1.1		7	-	-	0.02
	2	38-67	80	18	2	7.8	0.3	4.8	0.9	1.3		8	-	-	0.01
	3	67-105	75	21	4	8.0	0.3	14.9	0.9	1.2		17			
	4	105-162	63	28	9	8.0	0.5	15.6	1.0	1.4		18			
	5	162-220	73	23	4	8.3	0.8	12.8	0.9	1.3		15			
	6	220-240	85	15	0	8.3	0.7	4.7	0.8	1.2		6			

Pit NO.	Depth Cm	C:N	CaCO3 %	Olsen P PPm	ESP	SAR	Soluble cations (meq/l)				Soluble anions (meq/l)				
							Ca +Mg	K	Na	sum	CO3	HCO3	Cl	SO4	sum
5	0-38	-	0.1	0.4	15	3.1	1.1	1.0	2.3			0.23	1.5		
	38-67	-	0.2	0.4	16	2.6	1.4	0.8	2.2			0.19	1.5		
	67-105		0.3		7	2.7	1.4	0.8	2.3			0.18	1.5		
	105-162		0.1		7	3.8	1.4	0.8	3.2			0.22	1.6		
	162-220		0.1		8	7.4	1.8	0.9	7.1			0.35	1.6		
	220-240		-		20	6.1	1.5	0.9	6.8			0.39	2.3		

Auger No:	Labe No:	Depth Cm	coordinate		PH	ECe	Sand %	Silt %	Clay %
			N	E					
1	1	0-30	13°38'24.91"	25°19'17.60"	6.2	0.1	73	23	4
	2	30-60			6.5	0.2	74	22	4
	3	60-100			6.3	0.3	69	25	6
2	4	0-30	13°38'25.11"	25°19'15.50"	7.4	0.1	81	17	2
	5	30-60			6.9	0.1	77	21	2
	6	60-100			7.0	0.1	79	19	2
3	7	0-30	13°38'25.17"	25°19'13.31	6.7	0.1	80	16	4
	8	30-60			6.6	0.1	80	18	2
	9	60-100			7.0	0.1	76	20	4
4	10	0-30	13°38'25.25"	25°19'11.12"	7.2	0.1	82	16	2
	11	30-60			6.9	0.1	78	16	4
	12	60-100			6.9	0.1	80	16	4
5	13	0-30	13°38'23.97"	25°19'9.18"	7.1	0.1	80	18	2
	14	30-60			7.0	0.1	78	18	4
	15	60-100			6.9	0.1	78	18	4
6	16	0-30	13°38'23.71"	25°19'11.20"	7.0	0.1	79	17	4
	17	30-60			7.0	0.1	75	21	4
	18	60-100			6.9	0.3	74	22	4
7	19	0-30	13°38'23.48"	25°19'13.30"	6.9	0.1	81	17	2
	20	30-60			7.0	0.1	79	19	2
	21	60-100			7.0	0.2	73	23	4
8	22	0-30	13°38'23.30"	25°19'15.28"	7,0	0.1	79	19	2
	23	30-60			6,9	0.1	79	19	2
	24	60-100			7.3	0.2	75	23	2
9	25	0-30	13°38'23.05"	25°19'17.51"	6.7	0.1	78	18	2
	26	30-60			6.6	0.1	77	21	2
	27	60-100			7.0	0.1	79	19	2
10	28	0-30	13°38'21.24"	25°19'17.47"	6.6	0.1	78	18	4
	29	30-60			6.8	0.1	80	18	2
	30	60-100			6.9	0.1	80	18	2
11	31	0-30	13°38'21.38"	25°19'15.22"	6.8	0.1	80	16	4
	32	30-60			7.0	0.1	80	18	2
	33	60-100			6.6	0.1	80	16	4
12	34	0-30	13°38'21.61"	25°19'13.24"	7.1	0.1	82	16	2
	35	30-60			6.8	0.1	82	16	2
	36	60-100			6.4	0.1	80	16	4
13	37	0-30	13°38'21.76"	25°19'11.20"	7.3	0.1	82	16	2
	38	30-60			6.8	0.1	80	16	2
	39	60-100			6.4	0.1	78	18	4
14	40	0-30	13°38'21.90"	25°19'9.06"	6.5	0.1	80	18	2
	41	30-60			6.5	0.1	82	16	2
	42	60-100			6.7	0.1	78	20	2
15	43	0-30	13°38'22.02"	25°19'7.06"	6.7	0.1	80	16	2
	44	30-60			6.7	0.1	78	20	2
	45	60-100			6.5	0.2	80	18	4
16	46	0-30	13°38'20.17"	25°19'4.68"	7.0	0.1	80	16	4
	47	30-60			6.7	0.1	76	20	4
	48	60-100			6.7	0.1	75	16	4
17	49	0-30	13°38'20.12"	25°19'6.96"	7.2	0.1	78	18	4
	50	30-60			7.5	0.1	78	18	4
	51	60-100			7.0	0.1	78	18	4
18	52	0-30	13°38'19.95"	25°19'9.06"	7.0	0.1	78	20	2
	53	30-60			6.9	0.1	76	20	4
	54	60-100			6.5	0.1	76	20	4
19	55	0-30	13°38'19.77"	25°19'11.02"	7.2	0.1	76	22	2
	56	30-60			7.0	0.1	74	22	4
	57	60-100			7.0	0.1	74	20	6
20	58	0-30	13°38'19.48"	25°19'13.03"	6.9	0.1	78	20	2
	89	30-60			7.0	0.1	78	20	2
	60	60-100			6.8	0.1	78	20	2
21	61	0-30	13°38'19.14"	25°19'15.32"	6.8	0.1	78	20	2
	62	30-60			6.9	0.1	78	20	2
	63	60-100			6.8	0.1	76	22	2
22	64	0-30	13°38'19.08"	25°19'17.45"	7.0	0.1	76	22	2
	65	30-60			6.9	0.1	74	22	4
	66	60-100			6.7	0.1	70	26	4

23	67	0-30	13°38’16.96"	25°19’17.30"	6.9	0.1	80	16	4
	68	30-60			6.4	0.1	77	18	4
	69	60-100			6.5	0.1	75	21	4
24	70	0-30	13°38’17.19"	25°19’15.23"	6.8	0.1	77	21	2
	71	30-60			6.6	0.1	77	21	2
	72	60-100			6.8	0.1	77	21	2
25	73	0-30	13°38’17.38"	25°19’12.98"	6.9	0.2	80	16	4
	74	30-60			6.5	0.2	80	18	2
	75	60-100			6.6	0.2	75	21	4
26	76	0-30	13°38’17.61"	25°19’10.90"	6.9	0.1	82	16	2
	77	30-60			6.7	0.1	80	18	2
	78	60-100			6.9	0.2	78	20	2
27	79	0-30	13°38’17.76"	25°19’8.92"	7.1	0.1	80	16	4
	80	30-60			7.2	0.2	80	18	2
	81	60-100			7.1	0.1	80	18	2
28	82	0-30	13°38’18.14"	25°19’6.90"	6.9	0.2	83	15	2
	83	30-60			6.8	0.2	83	15	2
	84	60-100			6.9	0.1	80	18	2
29	85	0-30	13°38’18.33"	25°19’4.56"	7.0	0.1	79	19	2
	86	30-60			6.8	0.1	79	19	2
	87	60-100			6.6	0.1	79	19	2
30	88	0-30	13°38’16.32"	25°19’4.38"	6.9	0.1	80	18	2
	89	30-60			6.6	0.1	80	18	2
	90	60-100			6.7	0.1	80	18	2
31	91	0-30	13°38’15.98"	25°19’6.64"	6.7	0.1	82	14	4
	92	30-60			6.5	0.1	82	16	2
	93	60-100			6.3	0.1	80	18	2
32	94	0-30	13°38’15.83"	25°19’8.68"	6.9	0.1	80	18	2
	95	30-60			7.0	0.3	78	20	2
	96	60-100			6.8	0.1	74	24	2
33	97	0-30	13°38’15.60"	25°19’10.55"	7.0	0.1	84	12	4
	98	30-60			6.7	0.1	82	10	8
	99	60-100			6.9	0.2	82	14	4
34	100	0-30	13°38’15.49"	25°19’12.80"	6.9	0.1	81	17	2
	101	30-60			6.7	0.2	79	19	2
	102	60-100			6.8	0.3	79	19	2
35	103	0-30	13°38’15.32"	25°19’15.05"	7.0	0.1	78	18	4
	104	30-60			7.1	0.1	68	30	2
	105	60-100			6.9	0.1	72	26	2
36	106	0-30	13°38’15.12"	25°19’17.12"	7.3	0.1	80	16	4
	107	30-60			7.2	0.1	78	18	4
	108	60-100			7.0	0.1	60	32	8
37	109	0-30	13°38’14.77"	25°19’19.38"	6.9	0.1	76	20	4
	110	30-60			7.0	0.1	74	24	2
	111	60-100			7.0	0.1	70	26	4
38	112	0-30	13°38’16.70"	25°19’19.56"	6.9	0.1	80	16	4
	113	30-60			6.8	0.1	78	20	2
	114	60-100			6.6	0.1	82	20	2
39	115	0-30	13°38’16.64"	25°19’21.60"	6.9	0.1	78	18	4
	116	30-60			6.7	0.1	78	18	4
	117	60-100			6.8	0.2	76	20	4
40	118	0-30	13°38’14.60	25°19’21.48"	7.2	0.1	82	16	2
	119	30-60			6.9	0.1	81	17	2
	120	60-100			6.9	0.1	78	20	2
41	121	0-30	13°38’14.45"	25°19’23.16"	6.9	0.1	78	20	2
	122	30-60			7.0	0.1	79	19	2
	123	60-100			6.8	0.1	76	20	4
42	124	0-30	13°38’12.77"	25°19’21.48"	6.8	0.1	83	15	2
	125	30-60			7.1	0.1	81	17	2
	126	60-100			6.9	0.1	79	19	2
43	127	0-30	13°38’12.88"	25°19’19.32"	6.9	0.1	79	19	2
	128	30-60			7.0	0.1	83	15	2
	129	60-100			6.9	0.1	83	15	2
44	130	0-30	13°38’13.07"	25°19’16.82"	7.0	0.1	81	17	2
	131	30-60			6.5	0.1	79	17	2
	132	60-100			6.3	0.1	79	19	2
45	133	0-30	13°38’13.22"S	25°19’15.11"	6.7	0.1	80	18	2
	134	30-60			6.4	0.1	78	20	2
	135	60-100			6.2	0.1	78	20	2