

**CHARACTERISTICS, CLASSIFICATION AND AGRICULTURAL
POTENTIALS OF SOILS OF UPPER YEZAT MICRO WATERSHED,
NORTH WESTERN HIGHLANDS OF ETHIOPIA**

BY

TIBEBU CHEKOL

A Thesis Submitted to

**The College of Social Sciences, Department of Geography and Environmental
Studies**

**Presented in Partial Fulfillment of the Requirements for the Degree of Master of Arts
in Geography and Environmental Studies**

Addis Ababa University

Addis Ababa, Ethiopia

May 2014

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School of Graduate Studies

This is to certify that the Thesis prepared by Tibebu Chekol, entitled: Characteristics, Classification and Agricultural Potentials of Soil of Upper Yezat Micro Watershed and submitted in partial fulfilment of the requirements for the degree of Master of Arts compiled with the regulation of the University and meets the accepted standards with respect to originality and quality.

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Signature: _____

Date of Submission: _____

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ACKNOWLEDGEMENT

An impressive people are required to support the work of the research from beginning to finalizing. I am pleased to use this opportunity to express my appreciation to all of them. First of all, I would like to express my sincere gratitude to Dr. Mohammed Assen for his unreserved professional advice and guidance for the success of my research. My special thanks and sincere appreciation goes to Dr. Teshome Desta for his successive assistance.

I would like to extend my special thanks to Dr. Assefa Abegaz, Ato Melaku Tadesse, Fikade Wondimagegn, Admasu Bizuneh, Kumsa Bayisa and others people who are not mentioned here for their supportive advice.

Finally, I wish to express my sincere indebtedness to my mother Wzo. Fantaye Chekol, and dedicated this work to her.

ACRONYMS

AB	Angular blocky
Av.P.OI	Available Phosphorous-Olsen
Bas.Sa	Base Saturation
C/N	Carbon Nitrogen Ratio
CEC	Cation Exchange Capacity
Cf	Common fine
cmol (+) /Kg	centimoles per Kilogram
DAP	DIAMMONIUM PHOSPHATE
dS/m	decisiemens per meter
DTPA	diethylenetriamine pent acetate
EC	Electrical Conductivity
ESIF	Ethiopian Strategic Investment Framework
FR	Friable
GDP	Growth Domestic Product
GPS	Geographical Positioning System
ILRI	International Livestock Research Institute
masl	Meter Above Sea Level
ME	Medium
MoFED	Ministry of Finance and Economic Development
MoW	Ministry of Water Resource
OC	Organic Carbon
pH H ₂ O	pH of water

PL	Plastic
ppm	part per million
ST	Sticky
TN	Total Nitrogen
UNCED	United Nations Conference on Environment and Development
Vf	Very fine
VPL	Very plastic
VST	Very sticky
WE	Weak
WRB-FAO	World Reference Base -Food and Agriculture Organization

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ABSTRACT

Agriculture is the key pillar of the economy and ensures food security. The predominantly fragile soils, undulating land form, and lack of awareness among farmers are the existing challenges in maintaining soil fertility. In this regard, intensive studies of the overall soil characteristics were conducted to seek a solution for the impediments. The overall objective of this study is to characterize, classify and determine the agricultural potentials of the soils of the study area. The methodology employed a semi detailed grid survey, soil laboratory analysis and interpolation technique. Accordingly, this study examined the morphological, physical, and chemical characteristics of the soils in upper Yezat micro watershed, northwest of Ethiopia. The survey identified Eutric Cambisols, Eutric Leptosols, Vertic Luvisols and Eutric Vertisols. Cambisols and Luvisols were located on gentle slope land covering about 714.1 and 844.6 ha respectively. Both Eutric Regosols and Leptosols found on steep slope of the upper part of the micro watershed consisted of 603.2 and 717.7 ha respectively. Eutric Vertisols consisted of 1706.4 ha situated in gently to very gently sloping land in the lower part of the study area.

The soil color of most surface soils varies from dark brown to very dark gray, especially the foot slope is much darker than the upslope due the presence of organic matter. The soil texture ranges from clay loam to clay and the soil consistency for most of the surface soils was friable sub angular block structure and low bulk density indicate that the soils have good physical conditions for agricultural practices. The quantity of cation exchange capacity ranged from 25.85 to 45.52 cmol (+) Kg⁻¹ of soil for almost all surface soil horizons. Most of the subsurface soils were moderately to slightly acidic due to slight leaching of soil elements. Available phosphorous content was low to very low in most surface soils except for a very few profiles. The available micronutrients content of the surface soils was in the normal range for Fe, Mn, and Cu although Zn was deficient in the soils. In general, the study shows that the most of the soils show moderately to slightly acidic character due to slightly leaching soil elements. The morphological and the physical characteristics of the soils are good for ease of agricultural work and plant root penetration, and some of the sustainable land management interventions improved the land quality to a certain extent.

CHAPTER ONE

1.0 INTRODUCTION

1.1 General background

Agriculture is a key pillar of the country's economy and the most important source of growth. It's evident that the agriculture sector is one of the main user of the soil resources. Most of the agricultural activity is dependent on utilizing the soils in the crop production system. Agriculture, therefore food security of the country, rely on sustainable management of land resources. This sector accounts for almost 48 per cent of growth domestic product (GDP) and 90 percent of export earnings (MoFED, 2013). It is the major concern of all people because of the primary source of food for an increasing population. Poor soil fertility is the major cause of the country's declining agricultural productivity and persistent food insecurity. A major constraint for low food production has been a frequent decline in quality of the soil resources (Sanchez, 2001). Agricultural production system by its nature location specific and determined by the interaction of physical, chemical, biological and socioeconomic factors. Agriculture production is based on the management and utilizing of soils toward increasing production and productivity. Given emphasis on sustainable land management in general and soils in particular is therefore very critical to support growth and ensure food security.

Soils are one of the most important fundamental component which help to grow plants. It provides nutrients for plants for successful growth and better agricultural productivities. As basic resources for food production they should be managed in a way that minimize environmental deterioration and to be used for the present and the future generations (Brady, 2001). The main characteristics of soils are largely influenced by climate and living matter acting upon parent material weathered mineral or organic matter from which the soil develops as conditioned by topography through the length of time (Brady and Weil, 1999). However, this naturally formed soil characteristics changed by the process of land use and anthropogenic factors. As a result of this reasons soil losses particularly in the Amhara region accounts for about 1.9 billion tons per year (ILRI, 2000), of which 66 percent of the

total soil loss of the region resulted from poor land management. Given the predominant climatic conditions, topography and inherent fragile soils, the highland has continuously faced challenges in maintaining soil fertility. Today, there is a need to give more emphasis to reverse the situation through promoting and scaling up best land management practices. Appropriate soil fertility management coupled with soil and water conservation measures are played most important role to protect the soil from depletion.

To realize this condition, available information on characteristics of soils can help to manage the soil resources according to their management requirement and potential. As soil characteristics are affected by a number of natural and human induced factors need to be examined their quality, characteristics and management practice. Thus, a clear understanding of the variation of soils under natural conditions and proper planning play important role for agricultural development.

The information that is obtained from soil surveys used to transfer knowledge to agricultural experts' policy makers' development agents and farmers about soils and able to decided best alternative options for development. Farmers attempt to conserve the soil resources through soil and water conservation could be encouraging effort. However, farmers' active involvement were not supported with scientifically examined soil and land resources information. Providing detailed comprehensive guideline on soil and land resource information, would be useful to enhance the knowledge and experience of farmers and development agents. This will be coupled with technically proven and demand driven investments on soil resources and environmental management alternatives. As soil characteristics are affected by the wide range of natural and human induced factors, the extent of their effect on soil characterization and possible management practices need to be closely examined.

1.2 Statement of the problem

Inappropriate land use is a key problem that affected the soil and the sustainability natural resources. These problems have emerged as an issues of global concern over the last few decades. These situation have been given special prominence in Ethiopia to mitigate the

problems through participatory land management. However, such activities need to be supported by reliable soil and environmental information.

Information on soil characteristics and their management requirements is mostly obtained through soil survey or equally termed as natural resource survey (Soil Survey Staff, 1993). Soil survey information is necessary to group soils according to their characteristics and potentials for appropriate land use and management system. Most previous studies carried out on the Ethiopia soils are focused on potential agriculture area, integrated development master plan preparation and small scale soil association map preparation (Abayneh, 2005). Except very few academic research work and small scale irrigated agricultural development, most of the soil resource surveys are restricted to exploratory and reconnaissance level on different physiographic regions of the highlands and central rift valleys (MoW, 2008). However, inadequate information on land resources have influence the management aspects the soils. Hence, the concern of this study is to consider the overall soil characteristics and to classify them according their assumed genesis. As soils differ spatially in their characteristics, their agricultural potentials and management aspect also varied. Thus, in this study focused on the characteristics, classification and studying the agricultural productivity of the soils of the Upper Yezat micro watershed, northwestern Ethiopia.

1.3 objectives

The general objective of this study is to characterize, classify and determine the agricultural potentials of the soils of the study area. The specific objectives include the following:

- A) To study the morphological and physicochemical characteristics of the soils.
- B) To classify the soils according to world reference base for soil resource classification (FAO-2006).
- C) To determine the agricultural potentials of the soils and environment in general and soil quality change obtained from applied land management practices in the micro watershed

1.4 Limitation, scope and significance of the study

Previous soil survey studies in the study of soils are focusing on characterization and classification related to potential agricultural area, master plan preparation, soil fertility problems and soil association (Abayneh, 2005; Engdawork, 2002; Eylachew, 1999). They tried to touch some of the land management practices and soil characteristics. However, the soil characteristics are immense and they are played important role in quantitative evaluation of the spatial distribution of the soil in any defined micro watersheds. Under such circumstances, soil characterization coupled with best land management practice will be considered as an options to enhance land productivity. Thus, this study is designed to study the characteristics, agricultural productivity and the importance of land management practice in the micro watershed.

It's understandable that the overall task of soil survey is broad and multidimensional in terms application and approach. Within limited man power, time and scarce resource it is difficult to cover such wider area and broad tasks within a single tract of investigation. To accomplish this task an alternative option has be designed to limit the spatial extent of the study to a manageable size such as micro watershed level. Thus, because of these reasons the scope of study will be restricted to micro watershed level.

In general, the study area is selected as a soil categorization research area for three most important reasons. Firstly, there is the need for soil resources information for agricultural development. Secondly, the area is easily accessible and could be managed by the researcher. Finally, it is found imperative to study the agricultural potential and characteristics of the soils.

CHAPTER TWO

2.0 REVIEW OF LITRATURE

2.1 The soils of Ethiopia

Soil is produced by forces of weathering acting on parent material deposited by geologic agencies (Jenny, 1941). The kind of soil that develops depends on five major factors. These factors are the type of parent material, the climate under which soil material has existed, organisms, topography; and the length of time the forces of soil formation have acted on the soil material (Foth, 1984; Brady and Weil, 2002). Soil development by its nature goes through a complex processes of weathering that acted upon the content of one component or other in a particular horizon (Breemen and Buuman; 2002). The soil forming factors are interdependent; each modifies the effect of the others. As a soil forms, it is influenced by each of the above factors, but in its location one factor may be dominant and account for most of the soils properties. In places, a variation in any of the five factors results in a formation different kind of soil.

When assessing the soil resources in Ethiopia, one need to consider the varied interactions of soil with their spatial location, the altered natural condition in soil formation (Mesfine, 1998). Soils as the collection of natural bodies on the earth surface that may contains minerals and organic material in interactive combinations produced by physical chemical and biological processes (Gerrard,2000).The physical processes such as translocation, aggregation, freezing, expansion and contraction have much influence in soil formation (Brady and Weil, 1999).

All these processes occur largely in the soils of diverse environmental conditions. The processes of weathering not viewed in isolation stages of soil formation rather may occur simultaneously. Physical processes more important at the soil surface while chemical process can occur both the surface and below the surface of the soil (Tan, 1998; Boul etal., 1997). Chemical processes involved in hydration, hydrolysis, solution, oxidation and reduction (Brady, 2001; Birkeland, 1974). Soil development by its nature passed through

a complex process and formed by weathering that acted upon the content of one component in a particular horizon (Breemen and Buuman; 2002). Similarly, biological processes played important role in rocks and mineral weathering. This process is expected to largely occur mainly in the soils. This is because of the decomposition and respiration of roots and microorganisms and taking place in the surface than the subsurface horizons (Tan, 1998). The spatial distribution and the type of soil constituents vary widely from place to place. These processes probably applied in the Ethiopian conditions. According to Eylachew (1999) soil properties show great variations with altitude differences and soils of the highlands varied from those of the lowlands.

The soil surveys works in Ethiopia for the past five decades are generally concentrated in river basin irrigation and specific research area development (MoW, 2008; Abayneh, 2005). The survey works began in the country's by different institution and research organization. In Ethiopia the soil types and spatial distribution maps were prepared since 1970s at varied scale intensity. These mapped and identified soils are predominately developed from Precambrian basement rocks, limestone, sand stone basement material, colluvium and alluvium (FAO, 1984). About 19 major soil types are identified throughout the country. When look at the spatial location, distribution and characteristics of the soil they varied largely with change in slope, variation in landscape and present land use (Mohammed and Solomon, 2010; Sheleme, 2011).

Irrespective of occurrences of the soils that are found in western and central highlands of Ethiopia include Nitosols, Acrisols, Cambisols, Fluvisols, Luvisols and Vertisols. Gleysols and Histosols are found in areas flood plain that experiences extreme seasonal flooding during and after the rainy season (Asmamaw, 2008; FAO, 1984). In Northern highlands the type soils that occur almost similar to western highlands. This is because of long history of settlement and extensively cultivated for hundreds years and in turn the prolonged agricultural activities led to severe human induced erosion. This interventions responsible for the presence of existing soil characteristics. The major soil types in these area include Nitosols Acrisols Andosols, Phaeozems, Arenosols, Vertisols, Cambisols, Fluvisols and Leptosols (FAO, 1984; Basin study, 2008). These type of soils resulted from the interaction of parent material, climate and topography (Belay, 2008; Engdawork, 2002; Mohammed,

2008). The Chercher highlands the type of soils found influenced by the topography and climatic condition of the area (FAO, 1984; Mohammed, 2005). The prevailing climatic condition of this area being made suitable for agriculture and intensively cultivated for a decades. The major soil grouping are Cambisols, Vertisols, Nitosols, Fluvisols, Phaeozems, Luvisols and Leptosols. Uncultivated land soils in these area very rich in organic matter total nitrogen and available phosphorous while the chemical elements are declined for areas cultivated for prolonged time (Mohammed, et al., 2005).

In the southern and central Bale and Harerge the soil developed on a range of volcanic origin resulting from Trappean parent materials and limestone and sandstone (Mohr, 1971; FAO, 1984). Weinert and Mazurek (1984) noted that the basalt rock changed in to red and red brown to black silty loam as a result of weathering processes. In these areas the colluvium and alluvium origin was found on the flood plain of southern part particularly in Genale and Wabishebele river basin. Xerosols and Yermosols are found on the vast plain area. Arenosols, Solonchaks, Leptosols and Regosols are also predominant soils type in these areas. Whereas in southern part of Ethiopia the soil more dominantly developed from Precambrian basement materials. The soil types include Cambisols and Vertisols on flatter to moderately gentle slopes while Leptosols is found moderately steep slopes. In addition, in the rift valley of these area soils such as Andosols Leptosols and Solonchaks are very common (FAO, 1984).

The other soils types are Regosols which are formed unconsolidated materials and lacking diagnostic horizons and no soil profile development (FAO, 1998). These soils cover approximately 4 percent out of the total area coverage and occur on steep slopes and eroded land of northern and Chercher highlands. The water holding capacity of these soils are relatively minimal with clay loam textured. It has low medium cation exchange capacity CEC and in some areas low available phosphorous content (FAO, 1984). The presence of Regosols in the high land due to intensive cultivation and steeper land form. The shallow soil depth limited its important used for agricultural crop growing. Similarly, Leptosols are predominant soils type which covered about 16 percent of the total area of the country. It occurs in all climate as well as parent materials. The agricultural potential of this soil is limited by shallow depth.

With regard to some of specific characteristics, Vertisols are heavy clay soils occur on flat to nearly flat land that crack during the dry season and swell during the rainy season and causes pressure in the subsoil (Mesfin, 1998; Asnake, 1987). The chemical and physical characteristics the soil varied dependent on climate and specific characteristics. Nitosols are comprises almost 12 percent of the soils of Ethiopia, and found in gently sloping to steep land. According to FAO (1984) the color of Nitosols is reddish brown and good potential for agricultural crops. Similarly, Arcisols largely occur in high rainfall areas and has good physical structure but chemically poor. Luvisols more likely occur throughout the country where climatic conditions are favorable for clay movement. It has good potential for crop production. Cambisols are found in intensively cultivated land and agricultural productive soil. The soils are more chemically rich and had high agricultural potentials.

2.2 Soil degradation

Soil degradation is among the most critical environmental hazards in the current time. It is a common phenomenon in the Ethiopian highlands where it causes widespread soil quality degradation. Some factors for soil degradation are cultivation on steep slopes deforestation and overgrazing. Deforestation and overgrazing decrease the plant cover on the ground thereby exposing the soil surface to destructive rainfall.

Hurni (1986) indicated that in northern highlands of Ethiopia the amount of soil loss due to erosion estimated to be 42 metric tons per hectare per year. The soil removal always results nutrient loss and reduction of rooting depth and reduced the agricultural potential. Irrespective of their occurrence it is necessary to take appropriate land management practices in areas that are exposed to accelerated soil erosion.

The other most important factor responsible for land degradation is slope gradient at a site. Soil erosion is higher on the steeper slopes resulting poor soils characteristics restricting plant rooting depth. On the gentler slopes surface erosion is less and the soils materials are deeper. Soil depth has direct relation with erosion, slope and other soil properties (Engdawork, 2002; Belay, 1996). Soil depth influences the available nutrient storage capacity in the soil apart from plant root development (Buol, et al., 1997). The effect of slope gradient on soil depth is an important factor to consider in land management.

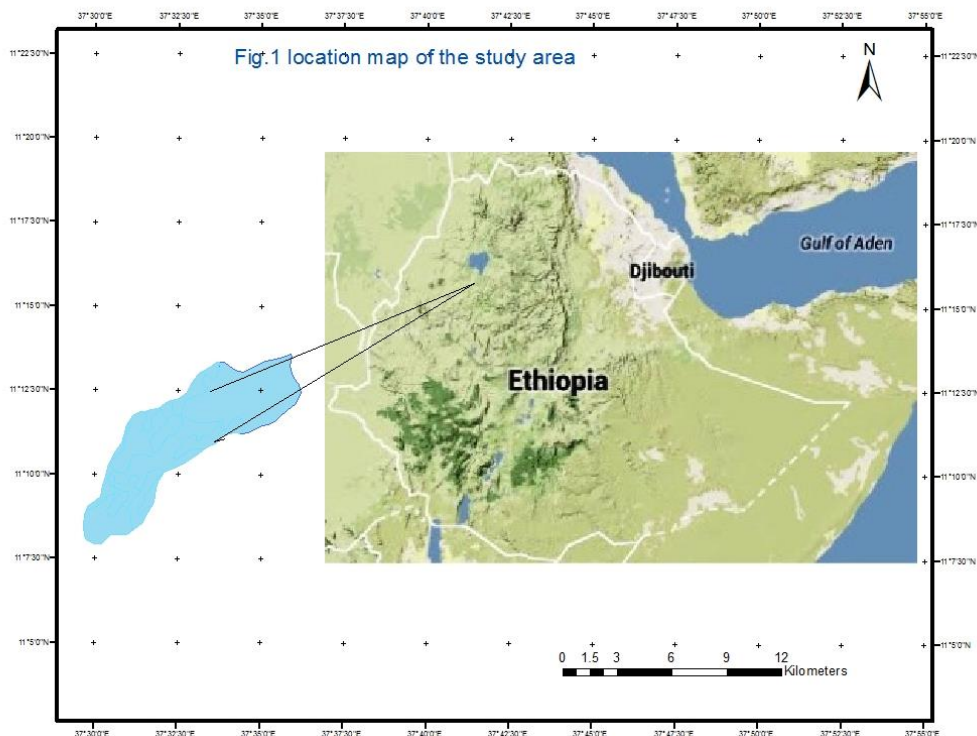
CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location and Geology

Upper Yezat micro watershed is found in the North Western part of Ethiopian highlands. The study area is geographically lying between $11^{\circ} 08' 22''$ to $11^{\circ} 09' 45''$ North latitude and $37^{\circ} 31' 32''$ E to $37^{\circ} 36' 33''$ East longitude (Fig. 1). The micro watershed has a wide range of topography soil and developed agricultural built area. The size of the watershed is estimated to be 4586 ha. The altitude ranges between 2200 and 2800masl.

The geology is dominated by the Precambrian basement rock underlying Mesozoic marine sediments and Tertiary flood basalt (Mohr, 1971). An integral part of the present day geology of upper Yezat fall into alkaline to transitional basalts forming shield in the tertiary highland volcanoes with minor trachyte and Ashenge formation deeply weathered alkaline and transitional basalt flows. It also fall into the late Paleozoic to early tertiary sediment and Cenozoic volcanic and associated sedimentary rocks.



3.2 Climatic conditions

Upper Yezat micro watershed has a moderate climate that is favorable for production of crop, livestock and multipurpose trees. In Ethiopia, the climate is varies with regard to its high extent of altitude and topographical features. The amount of rain fall increases with rise in altitude (FAO, 1984). The same is true for the study micro watershed. The main rainy season, rain fall is heaviest from June to mid of October. The short rainy season is not used for growing crops but farmers used for initial farm plot preparation. About 83.3 percent of the annual rainfall occurs in the main rainy season. The remainder 16.7 percent unevenly distributed throughout the rest of the year. From the meteorological data we observed that the study area received substantial amount of rainfall in most of the year. Adet Meteorological station 8 years rainfall data (2004-2011) indicated that the values of average annual rain fall for the study area was about 1213 mm (Appendix Table 14). In general based on altitude, annual rainfall, temperature and vegetation cover, the study area can be classified into moist Weyna Dega agro ecological zone.

Temperature is greatly influenced by the rapidly changing topography (FAO, 1984). The average maximum and minimum temperature shows that little amount of variation in most of the years. The minimum temperature in the rainy season varies considerably day to day, mainly because of periodic cold air movement. The values of average annual minimum temperature was 8.8 °C. The highest average maximum temperature was 29.6 °C while the lowest mean maximum temperature was 23.4 °C. The highest values of mean monthly temperature were recorded during the months of March and the lowest values of mean monthly temperature were during December and January. The meteorological data obtained from Adet meteorological station is shown in (Figure 2).

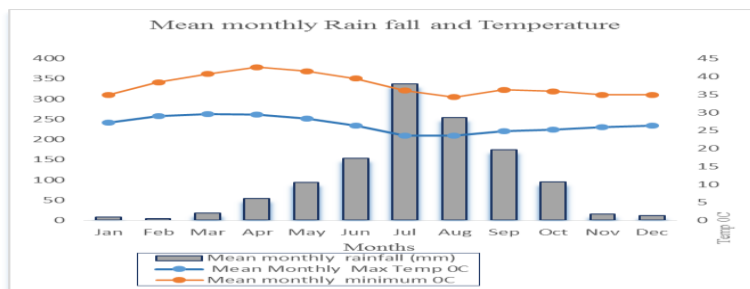


Fig. 2. Mean monthly rain fall and temperature.

3.3 Land use/ cover

In the study area, farmers are engaged in mixed farming system of crop and livestock production. About 91.9 percent of the area is predominantly used for crop production. The remaining 8.1 percent of the study area comprises of built area (homesteads), bushes and grazing land (Table1). The major crops grown in the area were Wheat, Barley, and Sorghum. Few scattered trees such as *Acacia Albida*, *Cordia African* and *Croton* are found on the farm land whereas, *Eucalyptus Camendulensis*, trees are grown around the home stead. Predominantly farmers apply chemical fertilizers such as DAP and UREA for most crops. They usually feed their live stocks crop residues which are obtained from harvested crop land. In addition, animals are allowed to graze on the cultivated land after the crop has been harvested.

Table 1. Land use /land cover

Land use type	Area (ha)	Percent
Bushes and grazing land	108	2.4
Grazing land	26	0.6
Built areas (Home steads)	238	5.2
Cultivated land	4214	91.9
Total	4586	100

3.4 Filed survey

3.4.1 Pre Field Work

Primarily to have a good picture of the study area a reconnaissance survey was conducted in the micro watersheds. For this purpose the national topographic map from Ethiopian Mapping Agency and satellite imageries was interpreted by the GIS application. The 150000 topo map was digitized to create a base map at 150000 scale. This map used as a survey map was supplemented with spot satellite image and other available relevant thematic maps such as agro ecology geology and land use cover maps.

3.4.2 Field Survey

After the reconnaissance survey, semi detailed grid field survey method (Young and Dent, 1976) was employed as a survey method. The micro watershed was classified into different soil map units were studied in the field. Then a preliminary interpretation of the prospective soils were undertaken. Observations were made with augers in each identified homogeneous and heterogeneous map units. In the auger survey a combination of grid and systematic survey was followed. Surface soil samples 0 to 30 cm depth were taken from representative map units in order to determine the soil fertility and the effect of land cover on soil characteristics. Soil descriptions was made according to the FAO-WRB, 2006) profile descriptions guideline. All the auger observations and pit descriptions were geo-referenced with the help of hand held GPS. In the field, core ring samples were collected. To measure the variation of some surface soil characteristics, composite samples were taken from representative land use patterns as identified in the field. The representative pits were described genetic wise and soils were classified in the field based the classification procedures. Sample was taken from recognized horizon of freshly opened representative soil profiles for soil element analysis. The samples were labeled and moved to the soil laboratory for analysis purpose. Prior to soil analysis the disturbed soil samples were air dried and ground to pass 2mm size mesh. For determination of soil particle size distribution, texture, available phosphorous, cation exchange capacity (CEC), exchangeable cations and available micronutrients the ground to pass through a (<2 mm) sieve whereas for the organic carbon and total nitrogen the fine ground passed through (<0.5mm) sieve.

These analyzed attributes were used to characterize the soils that were studied in the field and assess the general agricultural potentials of the soils. Once the soils classification and analyses were complete, a final soil map was produced by GIS digitizing and spatial analyst application tools at a scale of 1:50000.

3.5. Soil Laboratory analysis

The particle size was analyzed through hydrometer method (Bouyoucos, 1962). The bulk density of the core samples were oven dried at 105 °C for 24 hour. These values were calculated by dividing the oven dry of the soil to the volume of undisturbed soils which equal to the volume of core (Soil Survey Staff, 1991). The pH value is measured

potentiometrically in supernatant suspension pH- H₂O ratio of 1: 2.5 soil liquid mixture on 40 grams of ground pass through (<2mm) sieve. Then, the value was measure using pH meter. Similarly the EC was determined by adjusting the temperature with temperature correction factor and the value for EC was determined by reading conductivity meter.

The available phosphorous content of the soil was determined by 0.5 M sodium bicarbonate extraction solution pH 8.5 method of Olsen (Van Reeuwijk, 1993). The abundance of available phosphorous was measured on spectrophotometer. The soil total nitrogen content was determined by wet oxidation procedures of the Kjeldahl method (Bremner and Mulvaney, 1982). Organic carbon of the soil was determined by the wet combustion procedures of Walkely and Black method (Van Ranst, *et al.*, 1999). One gram of soil passed through (<0.5mm) sieve. Cation exchange capacity and exchangeable cations content of the soils were determined by 1M ammonium acetate pH-7 method according to the percolation tube procedures (Van Reeuwijk, 1993). The exchangeable cations Ca and Mg were determined in the ammonium acetate percolated by Atomic Absorption Spectrophotometer AAS whereas the exchangeable K and Na were determined by flame photometer. The available micronutrients contents of the soil were determined by DTPA extraction diethylenetriamine pentaacetate acid method (Tan, 1966). Zn, Fe, Mn and Cu was determined by this method DTPA as an extractant 20 gram of air dried ground passed through (<2mm) sieve. Finally, the content of micronutrient infiltrate was determined by Atomic Absorption Spectrophotometer (AAS) at different wavelength.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Morphological and physical characteristics

4.1.1 Soil Color, Texture and Depth

Profile 1 is located on moderately steep slopes (15 to 30 %). Soils represented by this unit consisted of moderately shallow depth and well drained soils. Both surface and subsurface horizons consisted of dark brown (7.5 YR3/3) color and overlaying clay loam texture. The dark brown color could be due to the presence of organic matter coatings. Soils represented by Profile 2 on the upper part of the micro watershed consisted of deep depth and well drained soils. This unit slope ranges from 15 to 30 percent. The color surface layer has dark (7.5 YR3/3) when moist while the subsurface horizons dark (10YR2/2) and dark brown (10YR2/2) respectively. The surface and subsurface horizons consisted of horizons 145 cm thick with clay texture. The lower part had dark reddish brown (5YR3/3) when moist. The dark reddish brown color of this surface could be due to iron oxides.

Profiles 3 and 7 were on side slopes and middle part of the study area. This unit was shallow depth and well drained soil. Slopes ranged from 5 to 10 percent and its clay loam textured soils. The Ap horizon of these profiles had dark brown (10YR3/3) and the subsurface horizon consisted of dark brown (7.5YR3/3) when moist. Pedon 4 consisted of very deep (>150cm) and formed well drained soils. This part had clay texture in the surface and subsurface horizons. It is located on sloping (5 to 10 %). The surface layers of these units have dominant dark brown (7.5YR 3/3). The A horizon has dark reddish brown (5YR3/4) while subsurface horizons contained dark reddish brown (2.5YR3/3). The soil depth of this layer is very deep (>150cm).

Profile 5 and 6 consisted chiefly of very deep (>150cm), moderately well drained soils that had clay texture in the surface and subsurface horizons. This unit is located on gently sloping (2 to 5 %). The Ap horizon of these units have dominant very dark gray (10YR

3/1). The A1 horizon has black (10YR2/1) whereas subsoil horizons had very dark gray (10YR3/1).

4.1.2 Soil structure and Consistence

The general condition of the soil structures indicated that there were considerable variation in the upper part and the lower part of the micro watershed profiles in terms of grade, size, and type. They were ranging from weak to strong, fine to coarser and sub to angular blocky structure between the upper and lower part of the micro watershed. Generally the examined consistence depends upon the moisture availability of the soils during field observation. The general trend shown that to some extent there was considerable variation in consistence when moving from the upper part and the lower part.

Profiles 1 had both surface and subsurface soils had weak fine to medium sub angular blocky structure, whereas the consistence were friable when moist, slightly sticky and plastic when wet both in surface and subsurface horizons. Profile 2 had moderate and medium sub angular blocky structure in surface soil whereas strong and medium sub angular blocky structure in the subsurface horizons. They consisted of both in surface and sub-surface soils friable, sticky and plastic when wet and moist respectively. The structure of profile 4 had moderate fine and medium sub angular blocky structure in the surface soil and strong fine to medium angular blocky in the subsurface horizons. In this horizons it had consistence friable (moist), sticky and plastic when wet. Profiles 5 and 6 relatively had soil structure ranging from strong, fine medium to very coarse angular blocky angular blocky structure. The upland profile 3 and 7 had both in surface soil and subsurface soils moderate; fine to medium sub angular structure.

Table 2. Morphological characteristics of soil mapping unit

Depth	Horizon	Color	Structure	Consistence Moist/Wet	Pores	Roots
Profile YP- 1.						
0-20	Ap	7.5YR3/3 Moist	WE,ME,SAB	FR,ST,PL	M f-c	M,f-c
20-45	A	7.5YR3/2 “	WE,ME,SAB	FR,ST,PL	Mf,Me	C,f
Profile YP-2.						

Depth	Horizon	Color	Structure	Consistence Moist/Wet	Pores	Roots
0-18	Ap	7.5YR3/3 Moist	MO,ME,SAB	FR,ST,PL	MF,Me	C, f-Me
18-59	A	10YR2/2 “	ST,FI, ME,SAB	FR,ST,PL	Mf,FMe	Vf, f-Me
59-80	B _{w1}	7.5YR3/3 “	ST,FI, ME,SAB	FR,ST,PL	Cf,F,Me	Vf, f-Me
80-145	B _{w2}	5YR3/3 “	ST,FI ME,SAB	FR,ST,PL	Vf,F	Vf, f
Profile YP-3						
0-10	Ap	10YR3/3 Moist	MO,FI,ME,SAB	FR,ST,SPL	M,f-Me	M,Me
10-25	A	7.5YR3/3 “	MO, FI,ME,SAB	FR,ST,SPL	Ff,Me	F,f-Me
Profile YP- 4.						
0-30	Ap	7.5YR3/3 Moist	MO, FI,ME,SAB	FR,ST,PL	Cf,Me	C,f-Me
30-65	A	5YR3/4 “	ST,FI ME,AB	FR,ST,PL	Cf,c	F,f-Me
65-130	B _{t1}	2.5YR3/4 “	ST,FI ME,AB	FR,ST,PL	Cf,c	F,f-Me
130-200	B _{t2}	2.5YR3/3 “	ST,FI ME,AB	FR,ST,PL	Cf,c	none
Profile YP- 5.						
0-30	Ap	10YR3/1 Moist	ST,FI ME,AB	FR,VST,VPL	C,F	C,F
30-120	A ₁	10YR2/1 “	ST,VCO, ME,AB	FR,VST,VPL	F,F	F,F
120-200	A ₂	10YR3/1 “	ST, ME,AB	FR,VST,VPL	None	none
Profile YP- 6.						
0-20	Ap	10YR3/2 Moist	ST, FI, ME,AB	FR,VST,VPL	C,f-Me	C,F
20-52	A ₁	10YR2/1 “	ST, VCO ME, ,AB	FR,VST,VPL	F,F	F,F
52-120	A ₂	10YR3/1 “	ST, CO, ME,AB	FR,VST,VPL	Vf,F	none
120-200	AC	10YR3/1 “	MO, CO, ME, AB	FR,ST,PL	Vf,F	
Profile YP- 7.						
0-15	Ap	7.5YR3/2 Moist	MO,FI ME,SAB	FR,ST,PL	Cf,Me	M,F
15-24	A	7.5YR3/4 “	MO,FI ME,SAB	FR,ST,PL	Ff,Me	Cf,Me

4.1.3 Soil bulk density and Available Water holding Capacity

The bulk density is a key physical property of soil material which changes in response to soil management practices. Soil bulk densities vary with the nature of the soil particles and contents of organic matter of the soils. Thus, bulk density is highly dependent on changes in topography, plant cover, swelling and water content of soils (Sumnar, 2000). The bulk

densities of both surface and sub-surface soils in profile 1, 4, 5 and 7 varied from 1.07 to 1.31 (low). The low bulk density of soils indicate that ease for agricultural practice and good plant growth.

The available water holding capacity (AWC) of profiles 1 was low both in surface and subsurface horizons. The AWC in profile 4 varied from low to very low both in surface and subsurface horizons, profile 5 had medium to low capacity surface and subsurface horizons respectively.

4.2 Chemical characteristics of the soil mapping unit

4.2.1 Soil pH

The pH value of surface horizon of profiles 1 is 5.6 (moderately acid). This could be as a result of the presence of aluminum and hydrogen compounds accounting for soil solution H^+ ions in moderately acid soils. Aluminum and hydrogen are mostly responsible for soil acidity (Brady and Weil, 1999). Profile 2 had pH value ranging from 5.7 to 5.9 (moderately acid) increasing in value with increasing in soil depth. Profile 3 had pH value of 6.1 (slightly acid) in both surface soil and subsurface horizons. Profile 4 is located in the midslope of the micro watershed and the pH value is 5.8 in surface soil (moderately acid). In this profile pH increased in the subsoil horizons. Profile 5 and 6 had pH values of 6.3 to 6.7 (Slightly acid to neutral) which is favorable for most agricultural crops (Landon, 1991).

In general, the soils are relatively moderately acidic as a result of leaching which has depleted the surface horizons base forming cations. The low pH value is likely to lead an increase in Al toxicity and it is commonly expected at low pH values < 5.5 (Landon, 1996).

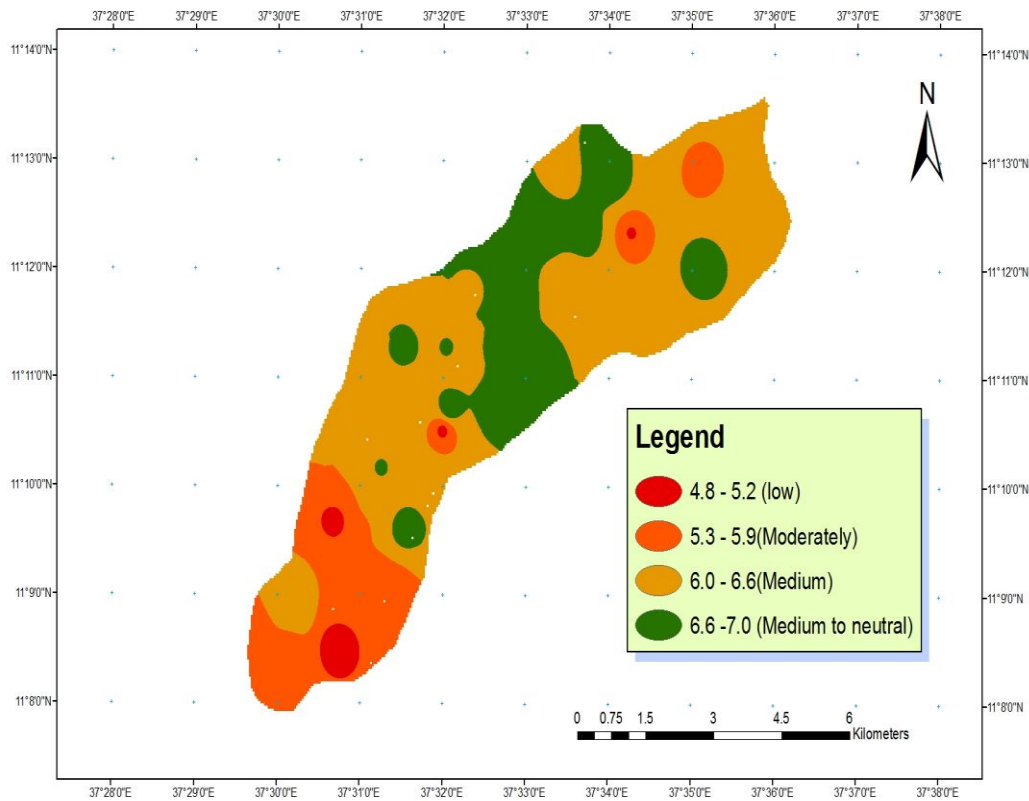


Fig. 3 Distribution of soil pH value

4.2.2 Organic Carbon and Total Nitrogen

Organic carbon (OC) of the soils generally decreased with depth of the profiles. The OC content in profile-1 ranged from 2.42 to 2.09 percent (low to very low). Profile 2 exhibited 1.99 percent (very low) at the surface soil, which decreased with increasing depth. The surface and subsurface of upslope land horizons had very low to low amount of organic carbon. The amount of OC in Profile 3 and 7 ranged from 0.72 to 1.74 (very low). Profile 4 had 1.11 percent (very low) in surface soil and showed a decreasing pattern in sub soil horizons whereas the amount in profiles 5 and 6 were almost 1.17 percent (very low). This could be as a result of removal of vegetation cover, repetitive harvesting of crops, and losses of these soil nutrients caused by soil erosion and slow onsite biological decomposition (FAO, 2005).

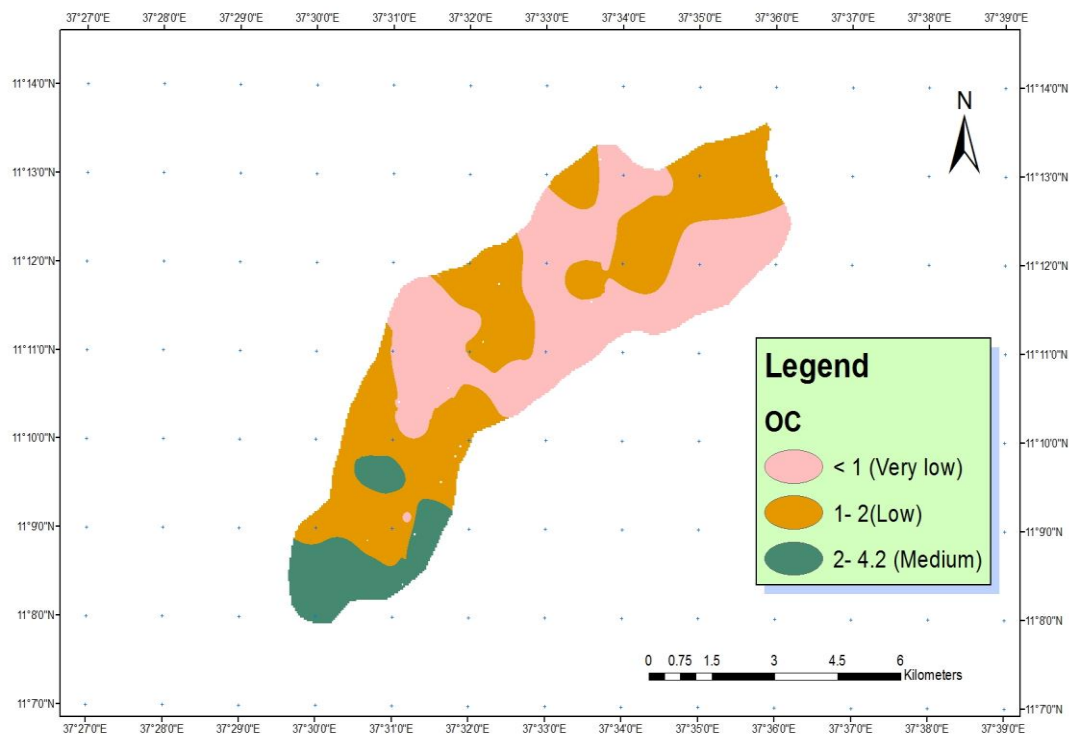


Fig.4 Organic carbon distribution

The amount of total nitrogen strongly decreased with increasing soil depth in almost all profiles. The presence of low to very low quantity of total nitrogen in most profiles could be as a result of variation in amount of organic matter available in the soil. It occurs in soil in the forms organic compounds, ammonium ions, which can occur as exchangeable cations (Landon, 1991). Generally, the total amount of nitrogen present in the soil ranged from 0.08 to 0.22 % which was very low to medium.

The detailed observation of total nitrogen content showed that low for profiles 4, 5 and 6, whereas medium for profiles 1, 2, 3, and 7 in the surface soil. The analyses indicate that medium nitrogen content of the soils have concentrated in the surface soils.

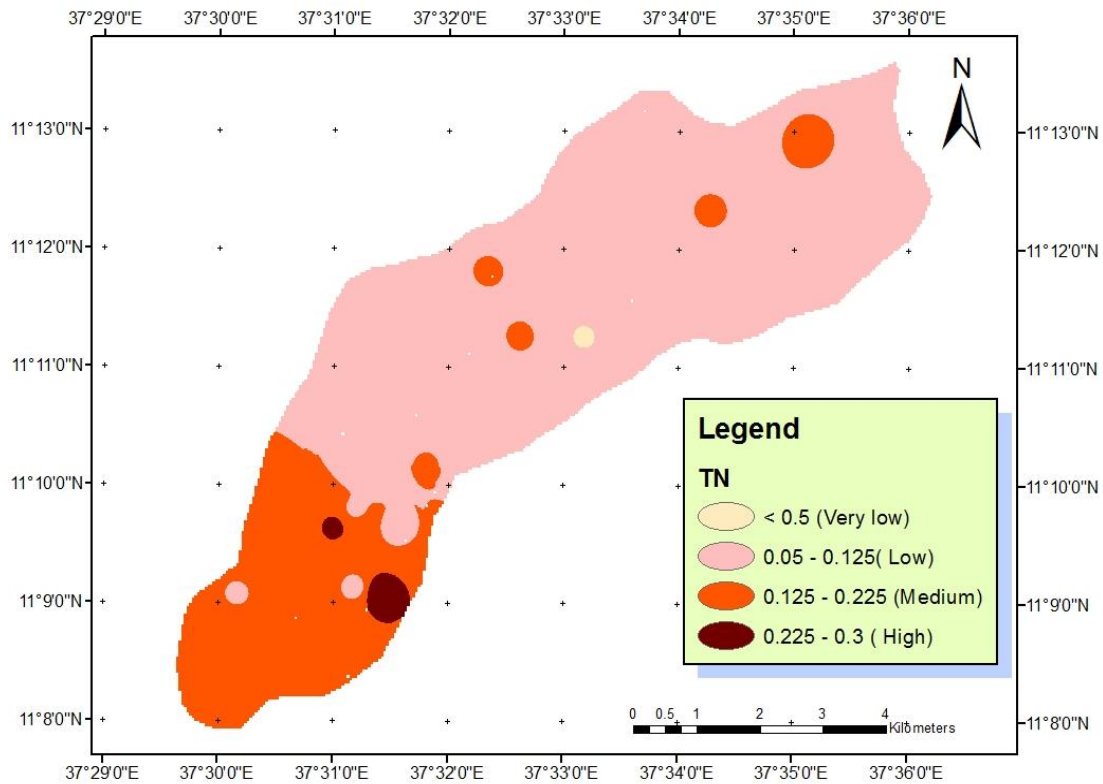


Fig.5. Total Nitrogen distribution.

4.2.3 Exchangeable Cations and Cation Exchange Capacity

The general trend of exchangeable bases in the studied profiles showed substantial increase with increasing depth of soil except one profile which is located in middle part, which showed a decreasing trend with increasing depth. This could be as a result of moderately high rainfall that was leaching the element from surface and accumulate them in the subsurface horizons. This well corresponds to the pH value of the respective horizons, where lower values were obtained in surface and relatively higher values in the subsoil horizons.

The amount of exchangeable sodium percent was low ($<2\%$) in surface soils throughout all profiles of the studied soils. It increased with increasing depth in profiles 1, 2, 3, 5, 6 and 7 but showed an irregular pattern in profile 4. The effect of high rainfall could be responsible for leaching the soluble cations to subsurface. The exchangeable potassium (K) contents

were low to moderate (0.18 to 0.7 cmol (+) Kg⁻¹ of soil) for all surface soils except profile 6 which was high. Exchangeable potassium in profiles 1, 2, 3, 4, 6, and 7 decreased with increasing soil depth of soils, whereas profile 5 showed an irregular pattern. The available K in surface soils of profiles 1 and 3 may not be sufficient for crop production as a result of leaching. Whereas in other surface horizons were sufficient for agricultural crop cultivation. Exchangeable potassium level was below 0.2 cmol (+) Kg⁻¹ of soil suggest that a plant response to application of potassium fertilizer is possible (Abbott, 1989).

The exchangeable calcium contents were high to very high (14.79 to 26.92 cmol (+) Kg⁻¹ of soil) in most of examined profiles. Exchangeable calcium in profiles 1, 2, 5, 6 and 7 are increased with increasing depth. The amount of exchangeable calcium (Ca) in subsurface horizons of profile 3 and 4 decreased in value and showed irregular pattern of variation. The exchangeable calcium in most of the surface and subsurface soil indicated a very high concentration and varied from 72.15 to 88.18% of the exchange sites.

The exchangeable magnesium ranged from 3.07 to 6.24 cmol (+) Kg⁻¹ of soil (high) in all examined surface soil horizons. In the sub soils, Mg content varied from 3.16 to 7.54 cmol (+) Kg⁻¹ soil. The amount of exchangeable magnesium in profiles 1, 5, 6 and 7 showed increasing pattern with increasing depth, while in subsoil of profiles 2, 3, and 4 decreases with increasing soil depth. The general trend of the exchangeable cations in the micro watershed was in the order of Ca > Mg > K > Na (Table 3).

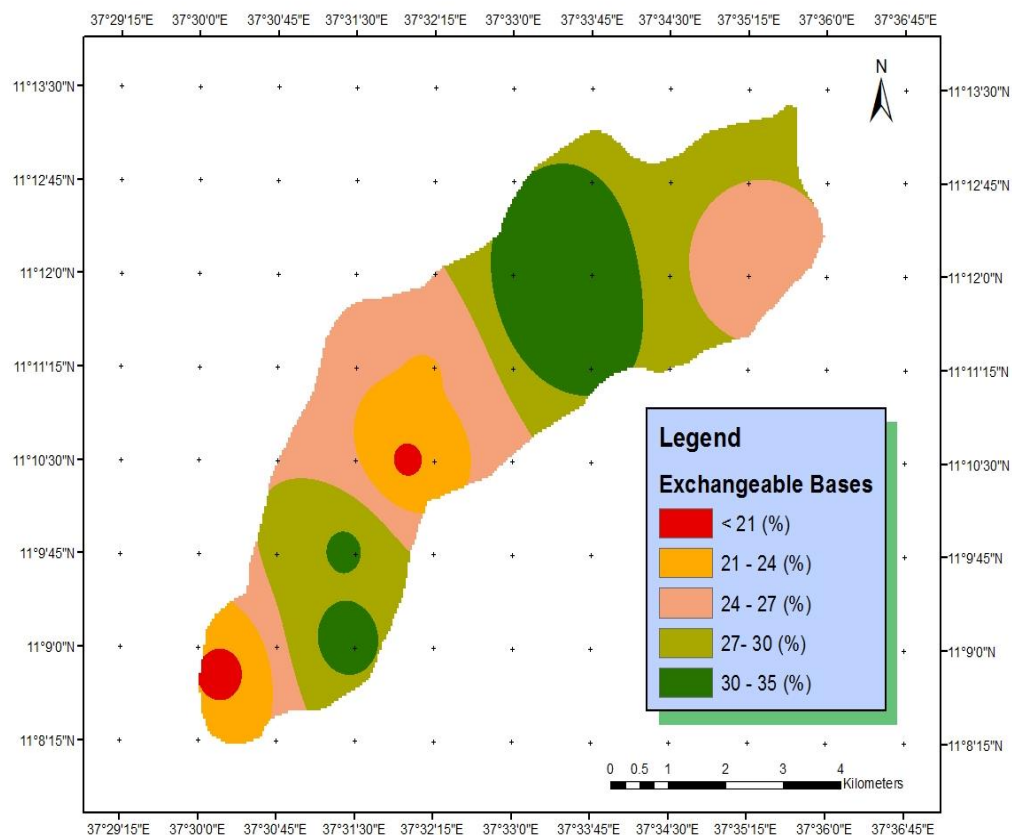


Fig. 6. Total exchangeable bases distribution

The cation exchange capacity of the surface layer ranged from 26.08 to 45.52 cmol (+) Kg^{-1} of soil. According to Landon (1991), classification for CEC in top soils can be rated as medium to very high. In all sub surface horizons, the CEC ranged from 21.7 to 45.38 cmol (+) Kg^{-1} of soil. It showed a decreasing pattern with increasing depth in profiles 1, 4, and 7. But profile 3 showed an increasing trend with increasing depth and profiles 2 and 6 had irregular patterns. Profile 5 had similar pattern both in surface and subsurface horizons.

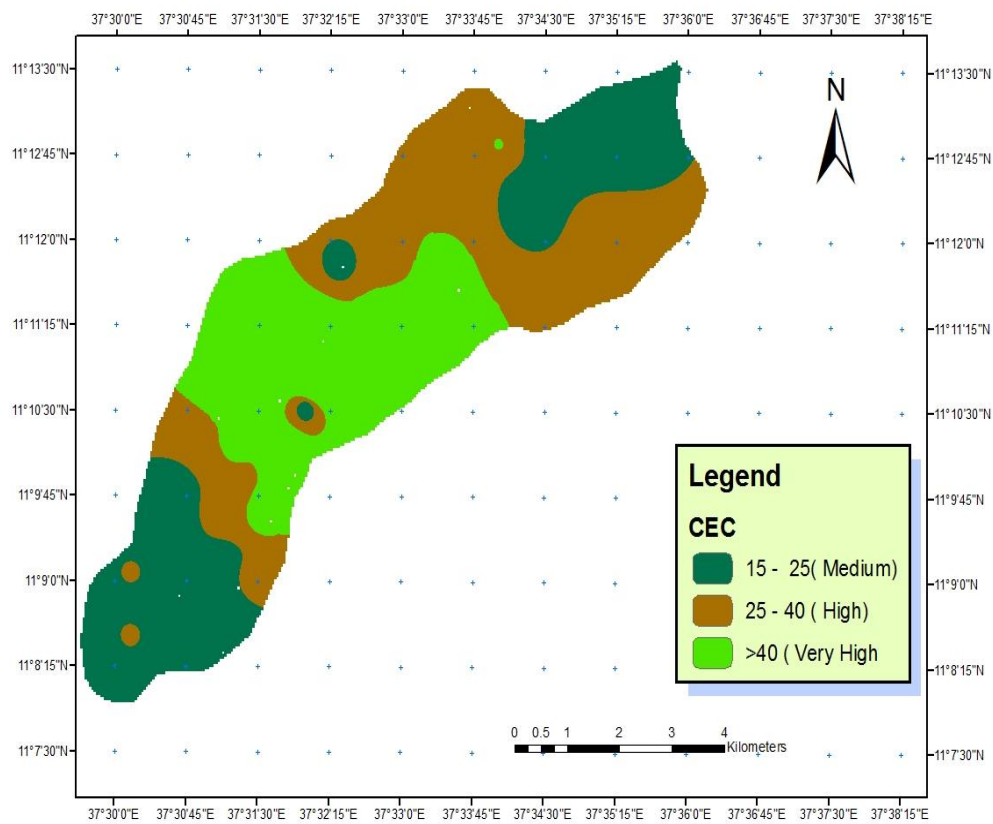


Fig. 7. Distribution of Cation Exchange Capacity.

4.2.4 Base saturation and Available phosphorous

Generally the percentage base saturation of the surface soil ranged from 57 to 97 (medium to high) and the subsurface horizons from 65 to 96 (medium to very high) in all surface horizons. Its percentage in upslope soils increases with increase in depth and it has irregular pattern for profiles located in middle and lower slope lands. Their amount relatively increased with increasing soil depth of upland and lower part. This indicated that there was leaching from surface to subsurface horizons. In general, the occurrence of higher percentage of the base saturation is almost in all soil profiles could be used as an indication of soil fertility and presence of high weatherable minerals in the soil (FAO-WRB, 2006).

Profile 1, had percentage base saturation value ranging from 72 to 88 which is high to very high and profile 3 varied from 89 to 97 both in the surface and subsurface horizons. Profiles 5 and 6 consisted of 62 to 85 in surface and subsurface soils. The value for the

surface and subsurface soils of Profile 4 ranged from 71 to 96 percent. The available phosphorous content of the surface soil ranged from 2.16 to 13.73 ppm and in the subsurface soil from 0.22 to 8.81 (very low to low). Profile 1 had high available phosphorous. The amount of available phosphorous value at upslope profiles decreased in the subsoil horizons and showed irregular pattern in the middle and lower parts of the studied area. The available phosphorous content of surface soil in profile 2 was very high (22.97 ppm). Almost in all profiles the value of the available P have relatively a decreasing pattern with increasing depth. The low available phosphorous with respect to soil depth could be associated to a decline in mineral matter in the same direction. In general, the available phosphorous content except profile 2 is considered to be very low.

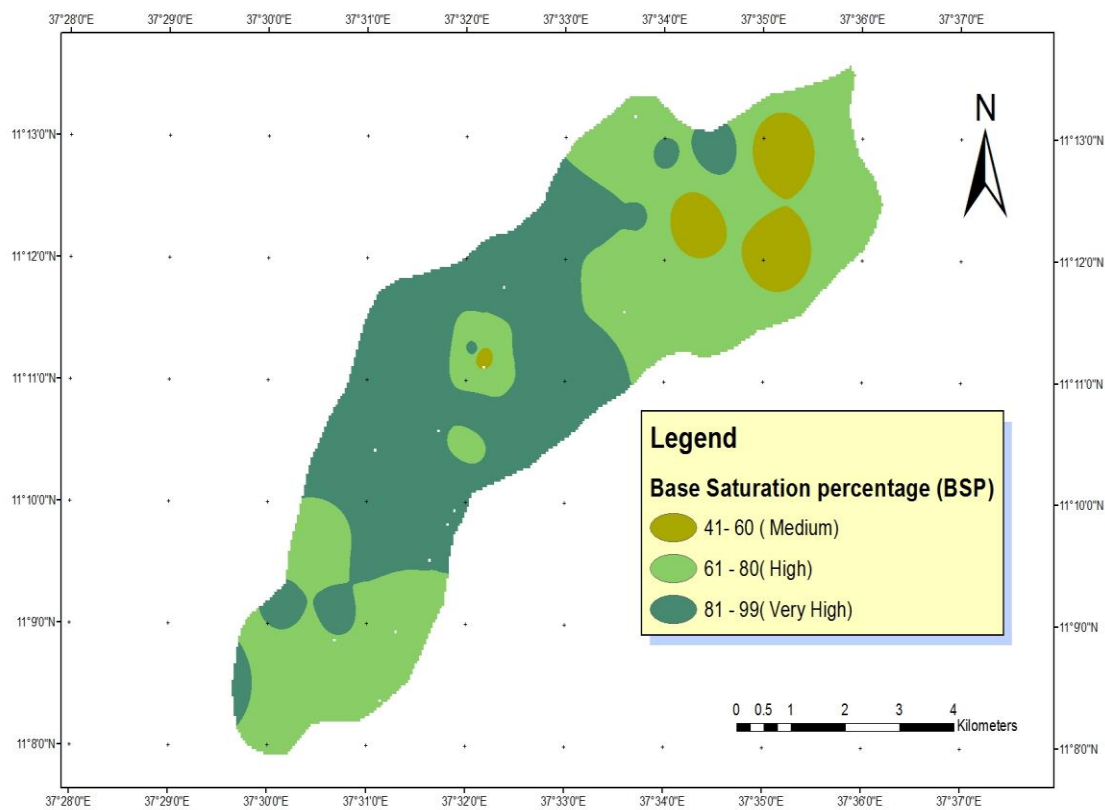


Fig.8. Bases saturation distribution

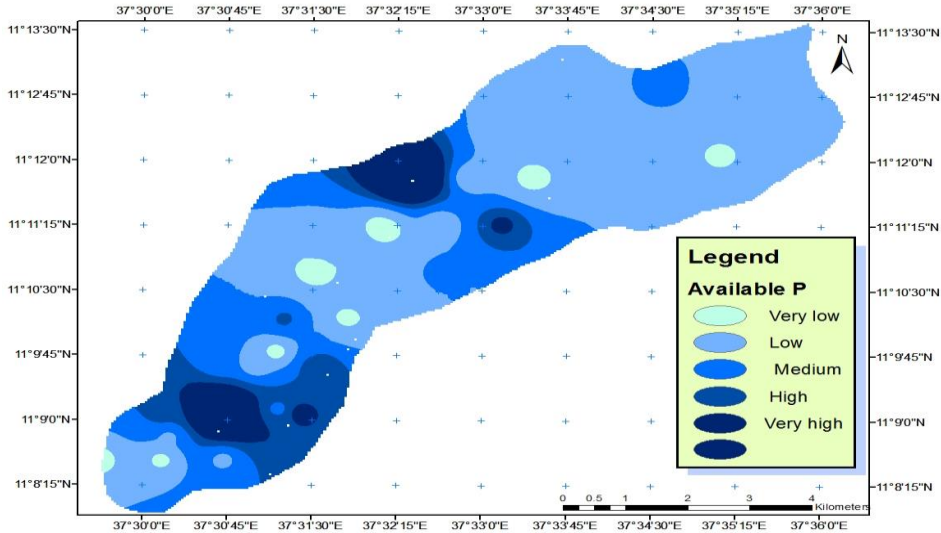


Fig.9. Distribution of available Phosphorous

4.2.5 Available Micronutrients

The available Iron (Fe) in the surface soil had value of 11.72 to 54.88 ppm and in subsurface horizons and it ranged from 5.86 to 76.78 ppm. The quantity of manganese (Mn) of surface soil ranged from 22.88 to 79.76 ppm and subsurface soil from 6.9 to 59.32 ppm. The surface horizons had available zinc (Zn) content of 0.06 to 2.05 ppm and subsurface soil had value of 0.14 to 1.36 ppm. The amount of copper (Cu) content of surface soil ranged from 0.18 to 4.71 ppm and subsurface soil 0.10 to 3.85 ppm.

The value of Fe showed a decreasing trend with increasing subsurface horizons in profile 1, 3 and 7 in upslope land and irregular pattern in middle part of the micro watershed. The Mn present in profile 2, 3,4,5,6, and 7 decreased with increasing depth. Mn content in Profile 1 increased with increasing soil depth. The available Zn contents of profiles 1, 2,4,5,6 and 7 decrease with increasing in the subsurface horizons. The quantity of Cu decreased with increasing depth in profile 1, 2, 3, 4, and 5 and showed an irregular pattern in profile 6.

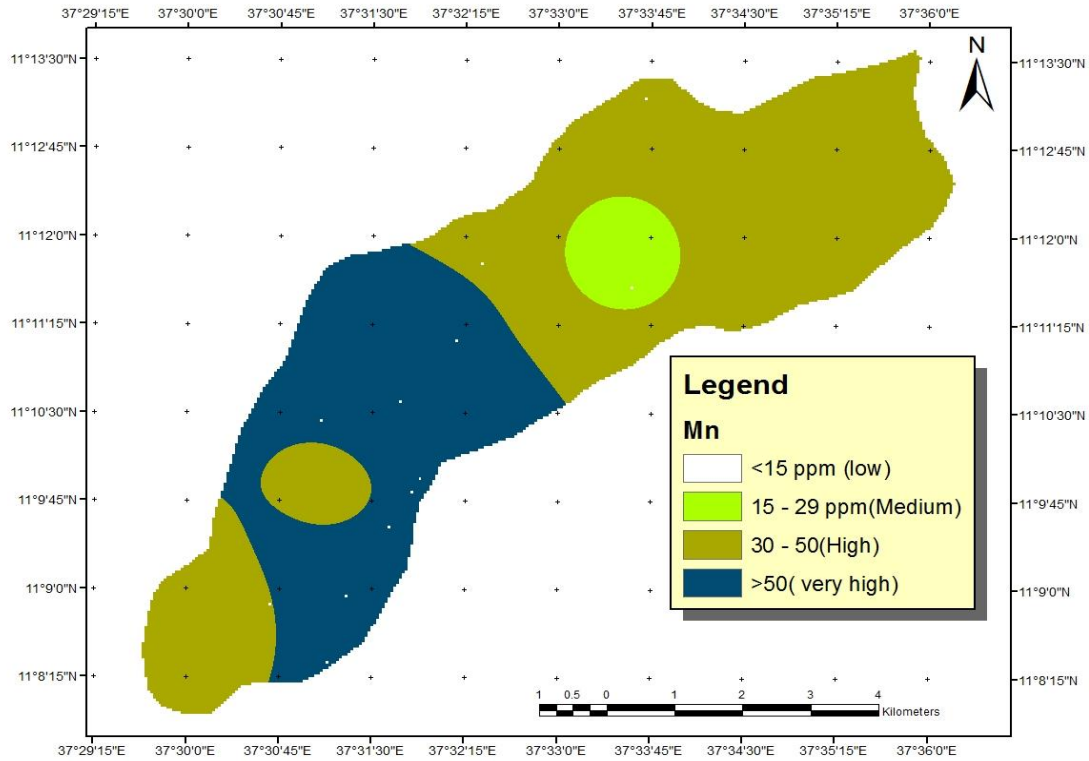


Fig.10. Distribution of available Manganese

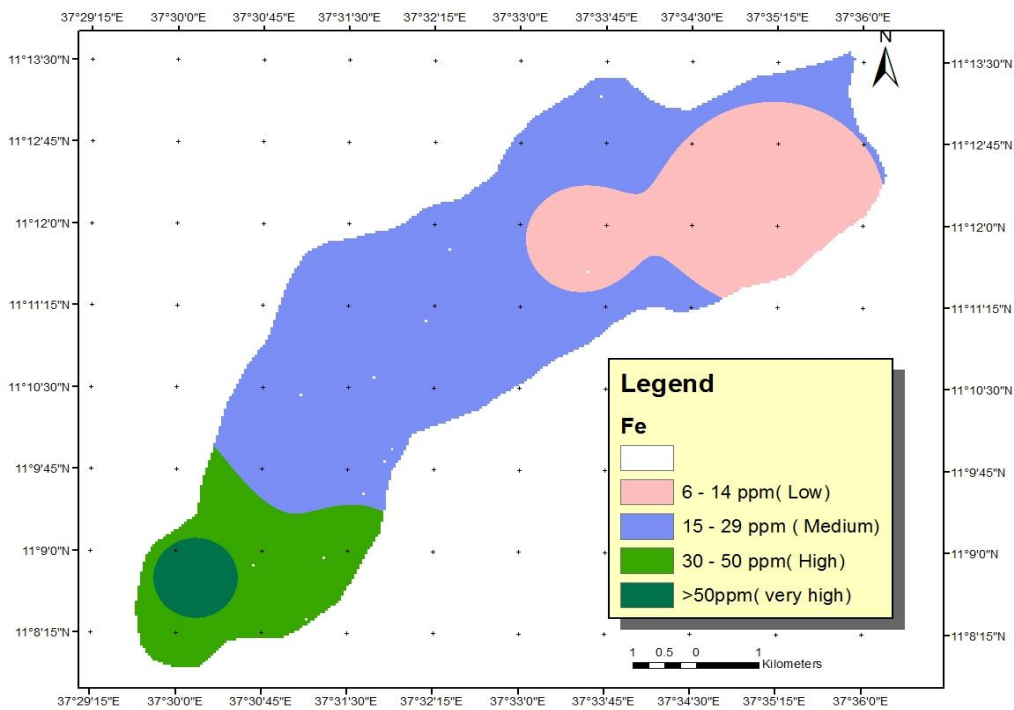


Fig.11 Distribution of available Iron

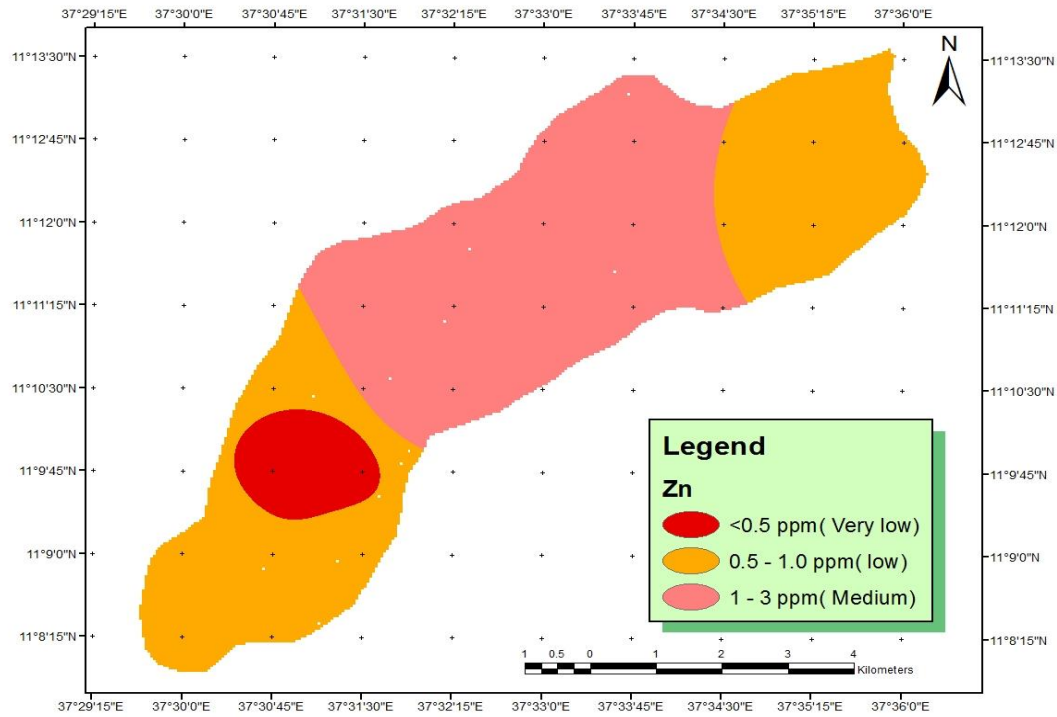


Fig.12. Distribution of available Zn.

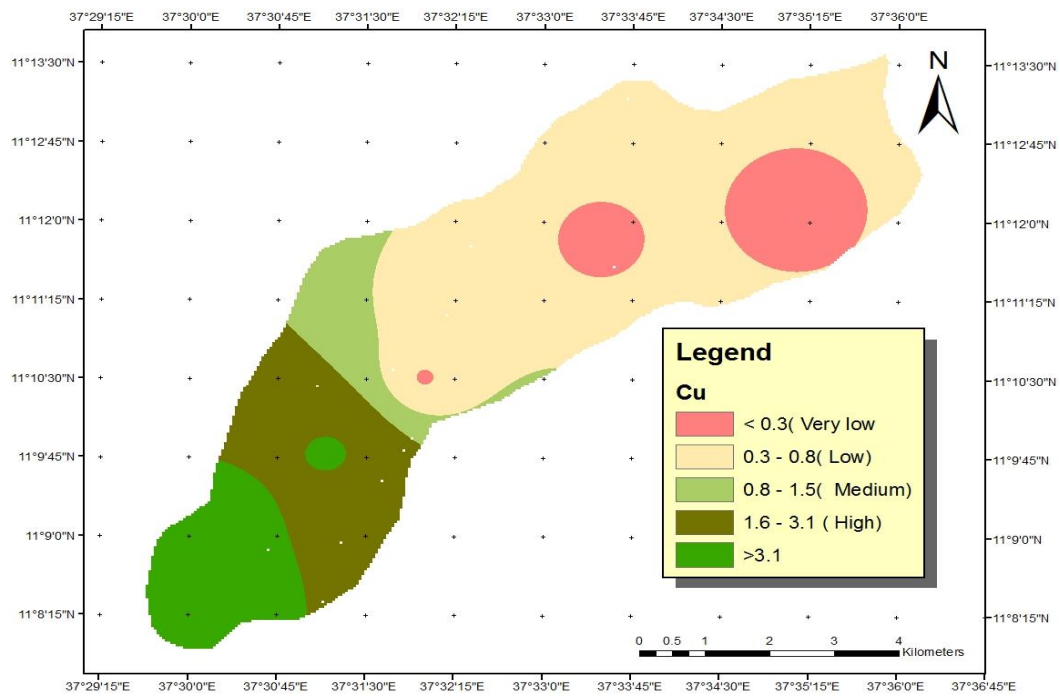


Fig.13. Distribution of available Copper

Table 3. Chemical characteristics of the soil mapping units

Horizon	Depth	pH	EC	Na	K	Ca	Mg	Sum
		H ₂ O	ds/m	cmol(+)/Kg				
Profile YP- 1								
Ap	0-20	5.6	0.063	0.54	0.18	14.79	3.07	18.58
A	20-45	5.6	0.087	0.2	0.19	16.75	3.36	20.49
profile YP- 2								
Ap	0-18	5.7	0.239	0.13	0.73	20.3	5.04	26.2
A	18-59	5.8	0.1	0.2	0.29	27.26	3.16	30.92
B _{w1}	59-80	5.9	0.183	4.56	0.23	23.03	4.1	31.92
B _{w2}	80-145	5.9	0.224	5.06	0.2	26.37	4.7	36.34
profile YP- 3								
Ap	0-10	6.1	0.096	0.24	0.24	26.92	4.48	31.89
A	10-25	6.1	0.203	0.52	0.12	25.63	4.13	30.39
Profile YP-4								
Ap	0-30	5.8	0.185	0.09	0.47	15.66	4.35	20.57
B _{t1}	30-65	5.9	0.174	0.11	0.28	11.36	3.6	15.35
B _{t2}	65-130	6.1	0.123	0.09	0.24	10.71	3.32	14.36
B _{t3}	130-200	5.9	0.042	0.11	0.41	16.77	4.35	21.63
Profile YP- 5								
Ap	0-30	6.7	0.179	0.24	0.55	21	6.24	28.03
A ₁	30-120	6.4	0.117	0.41	0.51	24.41	7.31	32.65
A ₂	120-200	6.9	0.104	0.48	0.58	26.15	7.54	34.75
Profile YP- 6								
Ap	0-20	6.3	0.127	0.09	0.95	20.03	3.84	24.9
A ₁	20-52	6.8	0.083	0.2	0.59	25.7	4.73	31.21
A ₂	52-120	6.7	0.088	0.3	0.69	24.71	4.72	30.43
AC	120-200	6.6	0.108	0.37	0.56	21.4	4.01	26.34
Profile YP-7								
Ap	0-15	6.6	0.2	0.2	0.59	17.32	5.79	23.89
A	15-25	6.3	0.283	0.22	0.51	22.16	7.22	30.11

Table 3. Chemical characteristics cont'd

Horizon	Depth	CEC cmol(+)/Kg⁻¹	Bas.Sa %	CEC/Clay
Profile YP- 1				
Ap	0-20	25.85	71.88	1.9
A	20-45	23.34	87.82	2.1
Profile YP- 2				
Ap	0-18	36.06	72.67	1.3
A	18-59	40.6	76.15	1.5
B _{w1}	59-80	39.64	80.52	1.54
B _{w2}	80-145	38.11	95.35	1.39
Profile YP- 3				
Ap	0-10	32.82	97.14	1.74
A	10-25	34.23	88.79	1.26
Profile YP- 4				
Ap	0-30	26.08	78.86	2.8
B _{t1}	30-65	21.7	70.74	3.73
B _{t2}	65-130	21.9	65.61	3.7
B _{t3}	130-200	22.48	96.23	3.6
Profile YP- 5				
Ap	0-30	45.52	61.59	1.56
A ₁	30-120	45.22	72.2	1.53
A ₂	120-200	45.38	76.57	1.61
Profile YP- 6				
Ap	0-20	37.72	66.01	1.78
A ₁	20-52	36.9	84.58	1.98
A ₂	52-120	45.02	67.59	1.62
AC	120-200	40.3	65.37	1.81
Profile YP- 7				
Ap	0-15	41.68	57.33	1.03
A	15-25	38.36	78.49	1.28

Table 3. Chemical characteristics cont'd

Horizon	Depth	T.N	O.C	C/N	Av.P.Ol.
	cm	%	%		ppm
Profile YP- 1					
Ap	0-20	0.22	2.42	11.08	13.73
A	20-45	0.19	2.09	11.11	8.81
Profile YP-2					
Ap	0-18	0.21	1.99	9.63	22.97
A	18-59	0.18	2.18	12.43	27.19
B _{w1}	59-80	0.07	0.79	11.66	27.73
B _{w2}	80-145	0.05	0.37	8.03	30.7
Profile YP-3					
Ap	0-10	0.14	1.5	10.39	2.16
A	10-25	0.08	0.72	9.3	1.73
Profile YP_ 4					
Ap	0-30	0.08	1.11	13.88	3.73
B _{t1}	30-65	0.05	0.49	10.36	8.11
B _{t2}	65-130	0.02	0.31	14.06	5.46
B _{t3}	130-200	0.02	0.23	13.03	3.84
Profile YP-5					
Ap	0-30	0.08	1.17	14.35	2.16
A ₁	30-120	0.05	0.56	11.4	0.22
A ₂	120-200	0.1	0.76	7.92	0.59
Profile YP- 6					
Ap	0-20	0.09	0.9	10.3	4.05
A ₁	20-52	0.02	0.3	14.06	0.76
A ₂	52-120	0.02	0.15	8.83	5.62
AC	120-200	0.01	0.09	7.11	5.89
Profile YP- 7					
Ap	0-15	0.18	1.24	7.01	2.16
A	15-25	0.11	0.83	7.85	1.03

Table 3. Chemical characteristics cont'd

Horizon	Depth	Fe	Mn	Zn	Cu
	cm	ppm	ppm	ppm	ppm
Profile YP- 1					
Ap	0-20	54.88	38.78	0.98	4.71
A	20-45	34.28	59.32	0.6	3.52
Profile YP-2					
Ap	0-18	34.56	79.76	1.03	2.33
A	18-59	76.78	32.84	0.71	3.85
B _{w1}	59-80	27.92	37.36	0.33	1.48
B _{w2}	80-145	23.5	47.1	0.4	0.93
Profile YP-3					
Ap	0-10	18.66	43.42	0.06	3.22
A	10-25	13.64	28.86	0.14	2.73
Profile YP_ 4					
Ap	0-30	17.46	66.3	2.05	0.28
B _{t1}	30-65	8.32	39.44	1.2	0.11
B _{t2}	65-130	10.76	43.78	0.9	0.1
B _{t3}	130-200	6.72	47.54	0.8	0.12
Profile YP-5					
Ap	0-30	12.58	22.88	2.01	0.21
A ₁	30-120	8.28	10.94	1.36	0.12
A ₂	120-200	8.88	6.9	1.2	0.13
Profile YP- 6					
Ap	0-20	11.72	33.28	1.13	0.18
A ₁	20-52	6.78	7.64	0.51	0.14
A ₂	52-120	6.78	8.56	0.65	0.18
AC	120-200	5.86	11	0.71	0.27
Profile YP- 7					
Ap	0-15	18.26	51.52	1.63	0.45
A	15-25	12.68	47.88	1	0.5

4.3. Soil classification

4.3.1 Soil map units

The soil map is used to compare the suitability land and dominant soil types in the micro watershed for agricultural use. Area of major soil types and major and micronutrients the current actual status were identified on the soil mapping unit. The surface and subsurface horizons and of the soils differed from one mapping unit to other in terms of nutrient levels, slope gradient and position, thickness, drainage and other characteristics that affect the management. In view of that, classification and the soil mapping units were derived from the morphological, physical and chemical characteristics of the soils. Five soil mapping units were identified in Upper Yezat micro watershed. The mapping units were given and classified according to the FAO-WRB (2006) system.

Accordingly, the diagnostic horizons and properties are compared with the WRB-FAO (2006) keys in order to find the representative soil group. For the second level of WRB classification, qualifiers are used as suggested in the employed classification guideline. The qualifiers for each soil type are associated with diagnostic horizons, chemical and physical characteristics of the soils.

4.3.1.1 Profile YP-1

Profile YP-1 located in upper part of the study area had moderately shallow depth with high base saturation percentage both in surface and subsurface horizon. Soils represented by this profile had high cation exchange capacity, dark brown color in the surface horizon. The horizons of the profile had high base saturation 87.82 %, high CEC and dark brown color characteristics. Hence, these soils are classified as Regosols as reference group with the suffix qualifiers of Eutric. It is then mapped and named as Eutric Regosols (Figure 14). The Eutric Regosols cover 603.2 ha of land (13.15%) of the micro-watershed (Table 4).

4.3.1.2 Profile YP-2

Profile YP-2 is located in moderately steep and gently sloping land and are deep soils. This soils located in up slope position have very high cation exchange capacity and base saturation percentage both in surface and subsurface horizon. Soils represented by the

profile have fine to medium angular blocky structure, high base saturation (70%) and dark in color soils in the surface horizon. This qualified for ochric diagnostic surface horizon. The subsoil horizon of the profile had very high base saturation, sub angular blocky and dark to very dark brown color characteristics. These characteristics qualified for cambic B diagnostic subsoil horizon. Hence, these soils are classified as Cambisols as reference group with the qualifiers of Eutric. It is then mapped and named as Eutric Cambisols (Figure 14). The Eutric Cambisols cover 714.1 ha of land (15.71%) of the micro-watershed (Table 4).

4.3.1.3 Profiles YP 3 and 7

Profiles YP-3 and YP-7 are located in moderately steep and gently sloping land and have shallow depth. This soils consisted high and very high cation exchange capacity and base saturation content both in surface and subsurface layers. These characteristics qualified for ochric diagnostic horizon. Hence, these soils are classified as Leptosols as reference group with the qualifiers of Eutric. It is then mapped and named as Eutric Leptosols (Figure 14). The Eutric Leptosols cover 717.7 ha of land (15.65%) of the micro-watershed (Table 4).

4.3.1.4 Profile YP-4

Profile YP-4 is located in moderately gentle sloping and had very deep soil. They consisted of high cation exchange capacity and base saturation content both in surface and subsurface horizons and decrease these quantities with increasing soil depth. Soils represented by this profile have angular blocky structure, high CEC and high base saturation, dark brown color and very fine surface crack characteristics in the surface horizon. This qualified for ochric diagnostic surface horizon. The subsoil horizon of the profile had very high base saturation, more than 30 percent clay, angular blocky structure and dark color. These characteristics qualified for argic diagnostic subsoil horizon. Hence, these soils are classified as Luvisols as reference group with the qualifiers of Vertic. It is then mapped and named as Vertic Luvisols (Figure 14). The vertic Luvisols contained 844.6 ha of land (18.42%) of the micro-watershed (Table 4).

4.3.1.5 Profile YP 5 and 6

Profile YP 5 and 6 are located in moderately gentle sloping and very deep soil. They consisted of high cation exchange capacity and base saturation content both in surface and subsurface horizons and decrease these quantities with increasing soil depth. Soils represented by this profile have angular blocky structure, very high CEC and high base saturation, more than 30 percent clay, common distinct silken sides and very dark gray color and characteristics in the surface horizon. This qualified for vertic diagnostic surface horizon. The subsoil horizon of the profile had very high base saturation, more than 30 percent clay, common distinct silken sides, and angular blocky and dark color characteristics. These characteristics qualified for vertic diagnostic subsoil horizon. Hence, these soils are classified as Vertisols as reference group with the qualifiers of Eutric. It is then mapped and named as Eutric Vertisols (Figure 14). The Eutric Vertisols contained 1706.4 ha of land (37.21%) of the micro-watershed (Table 4).

Table 4. Major Soil mapping units of the Upper Yezat Micro watershed.

Soil unit WRB-FAO(2006)	Symbol	Area	
		Ha	Percent
Eutric Cambisols	CMe	714.1	15.57
Eutric Leptosols	LPe	717.7	15.65
Vertic Luvisols	LVe	844.6	18.42
Eutric Regosols	RGe	603.2	13.15
Eutric Vertisols	VRe	1706.4	37.21
		4586	100

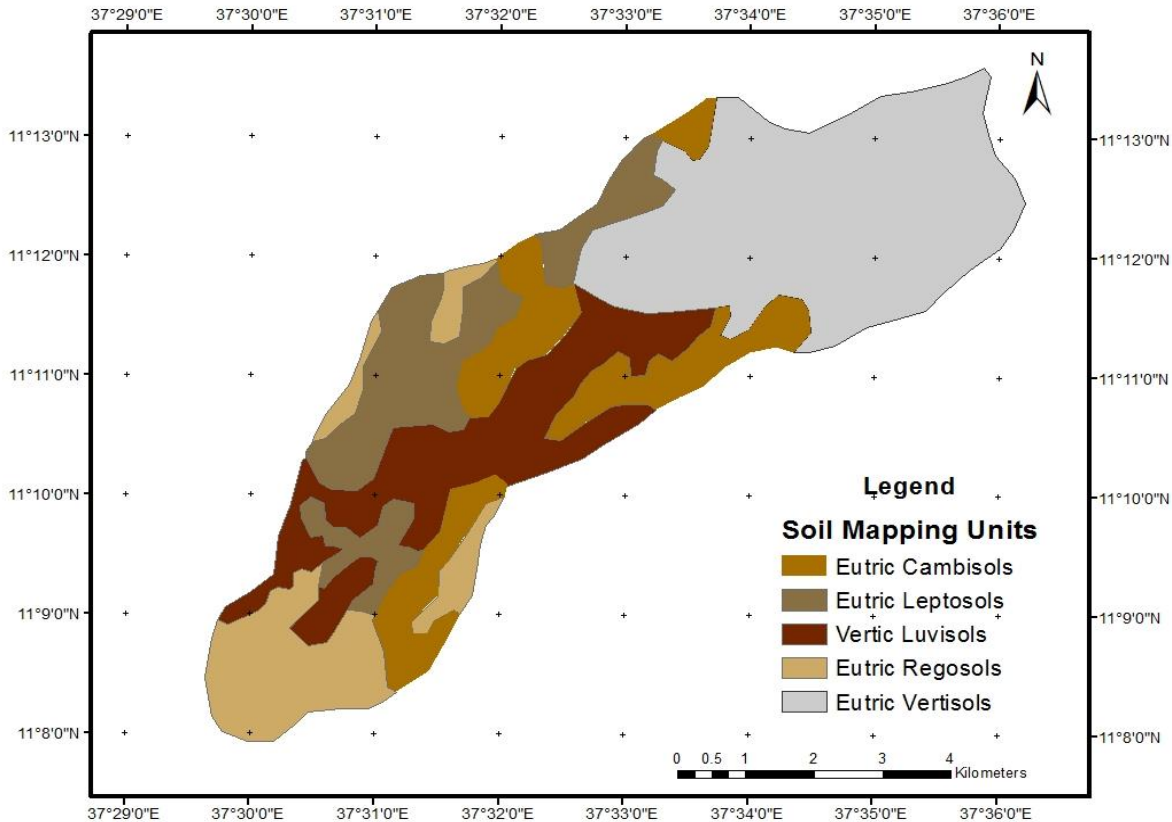


Fig.14. Soil mapping units of the Study area

4.4 Agricultural potential of the soils

The chemical potential of Eutric Vertisols of the micro watershed is important for agricultural production. The maximum availability of plants nutrients generally attained when reaction is possibly between pH 6.5 and 7.0 (Landon, 1991). This soil mapping unit had a reaction ranged from 6.6 to 6.9 and thus this range is suitable for almost all kinds of crops. However, the moderately poor drainage features of the soils require drainage improvement to remove excess water during the rainy season.

Eutric Cambisols located in the upper part had high quantity of available P indicate that the soils are good for plant growth. The physical and chemical characteristics of the soils were favorable for cultivating different types of crops. High to very high cation exchange capacity and base saturation allow the soil to retain added nutrients. Micronutrients in the surface soils were relatively in a normal range for Fe and Mn. Available Zn is relatively

medium whereas Cu was low in the surface soils. Toxicity is not a problem for this soil mapping unit. Cambisols are important agricultural soils and well suited almost for all perennial and cereal crops.

Vertic Luvisols are well suited for most agricultural crops. The cation exchange capacity and base saturation were medium to very high, although available phosphorous was relatively low. The soils pH was moderately to slightly acidic. Micronutrients in these units are relatively in normal range for Fe, Mn and Zn and medium for Cu particularly in the surface soils. Soil acidity was a limitation and require lime applications to raise the pH sufficiently for good growth of crops.

Eutric Regosols and Leptosols could be well suited for grazing, fodder tree and agricultural crops that are not affected by moisture deficit and shallow depth. The cation exchange capacity and base saturation were medium to very high. The available phosphorous was medium to very low for Eutric Regosols and Leptosols. These soil map units had pH value of moderately to slightly acidic and somewhat suitable for agricultural crop production. Micronutrients such as Fe, Cu and Mn are sufficient but Zn was low. The level of Zn and Cu contents for Eutric Leptosols located in upslope positions were medium to high respectively.

In general, moderate soil acidity is a limitation affecting crops that are non-resistant to acidic soil environment. Lime application is the main management concern to improve the acidity problem because the soils pH was slightly to moderately acidic. Residue management and appropriate conservation practices helps to improve soil moisture, control soil erosion and eventually improved soil fertility.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMENDATIONS

In Ethiopia agriculture is the key pillar of the economy and played most important role in sustainable development. The agricultural economic growth and food security of the country rely on proper management of the soil resources. Coupled with population pressure, land degradation is a major cause of declining the capacity of the soil resources and agricultural productivity. Given the predominant fragile soil, undulating land form, severe soil erosion and lack of awareness among farmers' challenges of soil management in general improving soil fertility in particular. Irrespective of the remarkable efforts made in the past years to study the characteristics and fertility status of the soils in different parts of the country, the intensity of investigation still remained behind the anticipated level. In this regard, the study attempted to examine the characteristics and classify the soils of Upper Yezat at semi detailed scale.

The result from the field survey and laboratory analysis revealed that five major soil types namely, Cambisols, Leptosols, Regosols, Vertic Luvisols and Vertisols are identified in the studied micro watershed. Soils were relatively varied in morphological, physical and chemical characteristics. The morphological characteristics of the soil types were influenced by topography and land use. The overall friable consistency and sub angular block structure indicate that these soils have good physical conditions for agricultural practices and plant growth. The color of most of surface soils varied from dark brown to very dark gray, especially the foot slope much darker than the upslope. The surface and subsurface soils of upslope land had lower pH than the lower part. High to very high CEC and percentage base saturation were observed in the upper and lower part of the micro watershed. The total nitrogen (TN) content was medium to very low, while Organic carbon (OC) content was relatively low in most soil types. The available zinc (Zn) in most surface soils were medium to low. Available phosphorous for all surface and subsurface horizons were very low except for Cambisols. Most of the soils in the micro watershed have a surface layer that is moderately to slightly acidic probably requiring moderate applications of lime to raise the pH sufficiently for good crop growth. These soils need the application

of nitrate, phosphorous and zinc sulfate fertilizer which should be based on the results of soil tests, the needs of the crops, and on the expected level of yields.

In addition, to minimize anthropogenic causes of land degradation, technical support to the intended farmers would be provided through the existing extension service system, and promote best practices and sustainable land management in the micro watershed. Implementation of best fit sustainable land and water management technologies and practices by farmers would be required in the micro watershed. Regular additions of crop residue, manure, and other organic material to improve structure and fertility of the soils. Thus, well integrated land management training for farmers and experts that are working at field level can help in determining the kinds and the required amounts of lime and fertilizer to apply, and regard to selection of best land management practices.

In general, the following are major recommendations based on the above discussions:

- The soil survey indicated that, the soils fertility in upper parts of study area ranged from slight to moderate. This due to soil erosion and poor farming practices. Hence, they require fertility management through supplying inorganic fertilizers such as DAP and Zinc sulfate.
- The soils should be enriched with organic materials like compost that will improve the soil productivity and ensures food security.
- Lime application is the main management concern to improve the soil acidity problem
- Continuous and proper management of the soils/degraded land through physical and biological soil conservation structures that are expected to improve soil fertility overtime could be indispensable.
- Awareness creation among farmers related to best land management and utilization alternatives.

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APPINDIX

Profile No. YP1: Environmental and horizon description

Soil type: WRB (2006): Eutric Regosols	External drainage: Well
Location: Adet Upper Yezat	Water table depth: Deep
Date of description: 2-11-2014	Moisture condition: Moist up to 20cm
Coordinate: 11 ⁰ 08' 47.42'' N	Surface stoniness: Many stones
37 ⁰ 30'14.5''E	Rock out crop: None
Elevation: 2669 meter	Surface cracks: none
Topography: Moderately steep	Distance between cracks: None
Major land form: Medium gradient hill	Land use/Vegetation: Cultivated land
Land element: Terrace	Human influence: Ploughing
Position: Lower	Flood frequency: None
Slope gradient: 15%	Evidence of erosion/deposition: Sheet active
Slope aspect & form: West & convex	Degree & activity of deposition: None
Micro topography: None	Parent materials: Weathered
Effective soil depth: 45 cm	
Drainage Class: Well drained	
Internal drainage: Never saturated	

Ap 0-20cm dark brown (7.5YR 3/3), when moist; clay loam; few fine to medium rock fragments; very friable when moist, sticky and plastic when moist; weak fine and medium sub angular blocky; common fine to medium roots; many fine and coarse pores; none calcareous.

A 20-45cm dark brown (7.5YR 3/2), when moist; clay; few fine rock fragments; friable when moist, sticky and plastic when moist; weak fine and medium sub angular blocky; common fine roots; many fine to medium pores; none calcareous.

Table 5, Analytical data for profile physical and chemical characteristics.

Horizon	Depth	pH	EC	Na	K	Ca	Mg	Sum
		H ₂ O	ds/m	cmol(+)/Kg				
Ap	0-20	5.6	0.063	0.54	0.18	14.79	3.07	18.58
A	20-45	5.6	0.087	0.2	0.19	16.75	3.36	20.49

Horizon	Depth	CEC	Bas.Sa %	CEC/Clay
		cmol(+)/Kg ⁻¹		
Ap	0-20	25.85	71.88	1.9
A	20-45	23.34	87.82	2.1

Horizon	Depth	T.N	O.C	C/N	Av.P.OI.
		cm	%	%	ppm
Ap	0-20	0.22	2.42	11.08	13.73
A	20-45	0.19	2.09	11.11	8.81

Horizon	Depth	Fe	Mn	Zn	Cu
		cm	ppm	ppm	ppm
Ap	0-20	54.88	38.78	0.98	4.71
A	20-45	34.28	59.32	0.6	3.52

Profile No. YP2: Environmental and horizon description

Soil type: WRB (2006): Eutric Cambisols	Water table depth: very deep
Location: Adet, Upper Yezat	Moisture condition: Moist up to 30cm
Date of description: 2-11-2014	Surface stoniness: Many stones and gravels
Coordinate: 11 ⁰ 09' 04.8''N 37 ⁰ 31' 24.3''E	Rock out crop: None
Elevation: 2678meter	Surface cracks: None
Topography: Rolling to moderately steep	Distance between cracks: None
Major land form: Medium gradient hill	Land use/Vegetation: Cultivated land
Land element: None	Human influence: Ploughing
Position: middle	Flood frequency: None
Slope gradient: 18%	Evidence of erosion/deposition: Sheet severe and active
Slope aspect & form: North	Degree & activity of deposition: None
Micro topography: None	Parent materials: Weathered
Effective soil depth: 145 cm	
Drainage Class: Well drained	
Internal drainage: Never saturated	
External drainage: Well	

Ap 0-18cm dark (7.5YR 3/3), when moist; clay loam; friable when moist, sticky and plastic when wet; moderate fine and medium sub angular blocky; common fine to medium roots; many fine and medium pores; none calcareous.

A 18-59 cm very dark brown (10YR 2/2), when moist; clay; friable when moist, sticky and plastic when wet; strong fine and medium sub angular blocky; very few fine to medium roots; many fine and few coarse pores; none calcareous.

B_{w1} 59-80 cm dark brown (7.5YR 3/3), when moist; clay; friable when moist, sticky and plastic; strong fine and medium sub angular blocky; very few fine to medium roots; common fine to medium pores; very few black both hard and soft manganese nodules; none calcareous.

B_{w2} 80-145 cm Dark reddish brown (5YR 3/3), when moist; clay; friable when moist, sticky and plastic when wet; strong fine and medium sub angular blocky; very few fine roots; very few fine pores; very few black both hard and soft manganese nodules; none calcareous.

Profile No.2 Analytical data

Table 6. Analytical data for profile physical and chemical characteristics.

Horizon	Depth	pH	EC	Na	K	Ca	Mg	Sum
		H ₂ O	ds/m	cmol(+)/Kg				
Ap	0-18	5.7	0.239	0.13	0.73	20.3	5.04	26.2
A	18-59	5.8	0.1	0.2	0.29	27.26	3.16	30.92
B _{w1}	59-80	5.9	0.183	4.56	0.23	23.03	4.1	31.92
B _{w2}	80-145	5.9	0.224	5.06	0.2	26.37	4.7	36.34

Horizon	Depth	CEC	Bas.Sa %	CEC/Clay
		cmol(+)/Kg ⁻¹		
Ap	0-18	36.06	72.67	1.3
A	18-59	40.6	76.15	1.5
B _{w1}	59-80	39.64	80.52	1.54
B _{w2}	80-145	38.11	95.35	1.39

Horizon	Depth	T.N	O.C	C/N	Av.P.Ol.
		cm	%	%	ppm
Ap	0-18	0.21	1.99	9.63	22.97
A	18-59	0.18	2.18	12.43	27.19
B _{w1}	59-80	0.07	0.79	11.66	27.73
B _{w2}	80-145	0.05	0.37	8.03	30.7

Horizon	Depth	Fe	Mn	Zn	Cu
		cm	ppm	ppm	ppm
Ap	0-18	34.56	79.76	1.03	2.33
A	18-59	76.78	32.84	0.71	3.85
B _{w1}	59-80	27.92	37.36	0.33	1.48
B _{w2}	80-145	23.5	47.1	0.4	0.93

Profile No. YP3: Environmental and horizon description

Soil type: WRB (2006): Eutric Leptosols	External drainage: Well
Location: Adet, Upper Yezat	Water table depth: very deep
Date of description: 2-12-2014	Moisture condition: slightly moist up to 0-30cm
Coordinate: 11°09'47.08''N 37°31'11.05''E	Surface stoniness: Many stones and gravels
Elevation: 2588meter	Rock out crop: None
Topography: Moderately steep	Surface cracks: none
Major landform: Medium Gradient Mountain	Distance between cracks: None
Land element: None	Land use/Vegetation: Cultivated land and acacia & Eucalyptus trees
Position: middle	Human influence: Ploughing
Slope gradient: 22%	Flood frequency: None
Slope aspect & form: North	Evidence of erosion/deposition: Sheet and gully active
Micro topography: None	Degree & activity of deposition: None
Effective soil depth: 40 cm	Parent materials: Weathered
Drainage Class: Well drained	
Internal drainage: Never saturated	

Ap 0-10cm dark brown (10YR 3/3), when moist; clay loam; friable when moist, sticky and slightly plastic when wet; moderate fine and medium sub angular blocky; common fine and rounded rock fragment; common fine roots; many fine and medium pores; none calcareous.

A 10-25cm dark brown (7.5YR 3/3), when moist; clay loam; friable when moist, slightly sticky and slightly plastic when wet; moderate fine and medium sub angular blocky; common fine and rounded rock fragment; very few fine roots; few fine and medium pores; none calcareous.

Table 7. Analytical data for profile physical and chemical characteristics.

Horizon	Depth	pH	EC	Na	K	Ca	Mg	Sum
		H ₂ O	ds/m	cmol(+)/Kg				
Ap	0-10	6.1	0.096	0.24	0.24	26.92	4.48	31.89
A	10-25	6.1	0.203	0.52	0.12	25.63	4.13	30.39

Horizon	Depth	CEC	Bas.Sa %	CEC/Clay
		cmol(+)/Kg ⁻¹		
Ap	0-10	32.82	97.14	1.74
A	10-25	34.23	88.79	1.26

Horizon	Depth	T.N	O.C	C/N	Av.P.Ol.
		%	%		ppm
Ap	0-10	0.14	1.5	10.39	2.16
A	10-25	0.08	0.72	9.3	1.73

Horizon	Depth	Fe	Mn	Zn	Cu
		ppm	ppm	ppm	ppm
Ap	0-10	18.66	43.42	0.06	3.22
A	10-25	13.64	28.86	0.14	2.73

Profile No. YP4: Environmental and horizon description

Soil type: WRB (2006): Vertic Luvisols	Water table depth: very deep
Location: Adet, Upper Yezat	Moisture condition: slightly moist
Date of description: 2-12-2014	throughout
Coordinate: 11° 10' 30.06'' N 37° 31' 59.9'' E	Surface stoniness: None
Elevation: 2469meter	Rock out crop: None
Topography: Flat to gently slopping	Surface cracks: None
Major land form: level plain	Distance between cracks: None
Land element: None	Land use/Vegetation: Cultivated land and Acacia, Croton & Eucalyptus trees
Position: middle	Human influence: Ploughing
Slope gradient: 7%	Flood frequency: None
Slope aspect & form: South	Evidence of erosion/deposition: Sheet moderate active at present
Micro topography: None	Degree & activity of deposition: None
Effective soil depth: 200 cm	Parent materials: Weathered
Drainage Class: well drained	
Internal drainage: Never saturated	
External drainage: well	

Ap 0-30cm dark brown (7.5YR 3/3), when moist; clay loam; friable when moist, sticky and plastic when wet; moderate fine to medium sub angular blocky; common fine to medium roots; common fine and medium pores; none calcareous.

A 30-65cm dark reddish brown (5YR 3/4), when moist; clay; friable when moist, sticky and plastic when wet; strong fine to medium angular blocky; few fine to medium roots; common fine and coarse pores; none calcareous.

B₁₁ 65-130 cm dark reddish brown (2.5YR 3/4), when moist; clay; friable when moist, sticky and plastic when wet; strong fine to medium angular blocky; few fine to medium roots; common fine and coarse pores; few black manganese nodules; none calcareous.

B₁₂ 130-200 cm dark reddish brown (2.5YR 3/3), when moist; clay; friable when moist, sticky and plastic when wet; strong fine to medium angular blocky; common fine and coarse pores; common black manganese nodules; none calcareous

Table 8. Analytical data for profile physical and chemical characteristics.

Horizon	Depth	pH	EC	Na	K	Ca	Mg	Sum
		H ₂ O	ds/m	cmol(+)/Kg ⁻¹				
Ap	0-30	5.8	0.185	0.09	0.47	15.66	4.35	20.57
B _{t1}	30-65	5.9	0.174	0.11	0.28	11.36	3.6	15.35
B _{t2}	65-130	6.1	0.123	0.09	0.24	10.71	3.32	14.36
B _{t3}	130-200	5.9	0.042	0.11	0.41	16.77	4.35	21.63

Horizon	Depth	CEC	Bas.Sa %	CEC/Clay
		cmol(+)/Kg ⁻¹		
Profile YP- 4				
Ap	0-30	26.08	78.86	2.8
B _{t1}	30-65	21.7	70.74	3.73
B _{t2}	65-130	21.9	65.61	3.7
B _{t3}	130-200	22.48	96.23	3.6

Horizon	Depth	T.N	O.C	C/N	Av.P.Ol.
		%	%		ppm
Ap	0-30	0.08	1.11	13.88	3.73
B _{t1}	30-65	0.05	0.49	10.36	8.11
B _{t2}	65-130	0.02	0.31	14.06	5.46
B _{t3}	130-200	0.02	0.23	13.03	3.84

Horizon	Depth	Fe	Mn	Zn	Cu
		ppm	ppm	ppm	ppm
Ap	0-30	17.46	66.3	2.05	0.28
B _{t1}	30-65	8.32	39.44	1.2	0.11
B _{t2}	65-130	10.76	43.78	0.9	0.1
B _{t3}	130-200	6.72	47.54	0.8	0.12

Profile No. YP5: Environmental and horizon description

Soil type: WRB (2006):	Eutric Vertisols	Water table depth:	very deep
Location:	Adet Upper Yazet	Moisture condition:	slightly moist throughout
Date of description:	2/13/2014	Surface stoniness:	None
Coordinate:	11 ⁰ 11'48.06''N 37 ⁰ 33'26.9''E		
	Elevation: 2382 meter	Rock out crop:	None
Topography:	Undulating to gently slopping	Surface cracks:	None
Major landform:	level plain	Distance between cracks:	None
Land element:	None	Land use/Vegetation:	Cultivated land and Acacia tree
Position:	middle	Human influence:	Ploughing
Slope gradient:	4%	Flood frequency:	None
Slope aspect & form:	South East	Evidence of erosion/deposition:	Sheet & gully
Micro topography:	None	Degree & activity of deposition:	None
Effective soil depth:	200 cm	Parent materials:	Weathered
Drainage Class:	Moderately well drained		
Internal drainage:	Not known		
External drainage:	slow		

- Ap 0-30cm very dark gray (10YR 3/1), when moist; clay; firm when moist, very sticky and very plastic when wet; strong fine and medium angular blocky; common distinct silken sides; few black both hard and soft manganese nodules; common fine roots; common fine and medium pores; none calcareous.
- A₁ 30-120 cm black (10YR 2/1), when moist; clay; firm when moist, very sticky and very plastic when wet; strong very coarse angular blocky; common distinct silken sides; few black soft manganese nodules; few fine roots; few fine and few medium pores; none calcareous
- A₂ 120-200 cm very dark gray (10YR 3/1), when moist; clay; friable when moist, very sticky and very plastic when wet; strong medium and coarse angular blocky; common distinct slickensides; few black soft manganese nodules; very few and fine pores; none calcareous.

Table 9 Analytical data for profile physical and chemical characteristics.

Horizon	Depth	pH	EC	Na	K	Ca	Mg	Sum
		H₂O	ds/m		cmol(+)/Kg⁻¹			
Ap	0-30	6.7	0.179	0.24	0.55	21	6.24	28.03
A ₁	30-120	6.4	0.117	0.41	0.51	24.41	7.31	32.65
A ₂	120-200	6.9	0.104	0.48	0.58	26.15	7.54	34.75

Horizon	Depth	CEC	Bas.Sa %	CEC/Clay
		cmol(+)/Kg⁻¹		
Profile YP- 5				
Ap	0-30	45.52	61.59	1.56
A ₁	30-120	45.22	72.2	1.53
A ₂	120-200	45.38	76.57	1.61

Horizon	Depth	T.N	O.C	C/N	Av.P.OI.
	cm	%	%		ppm
Ap	0-30	0.08	1.17	14.35	2.16
A ₁	30-120	0.05	0.56	11.4	0.22
A ₂	120-200	0.1	0.76	7.92	0.59

Horizon	Depth	Fe	Mn	Zn	Cu
	cm	ppm	ppm	ppm	ppm
Profile YP-5					
Ap	0-30	12.58	22.88	2.01	0.21
A ₁	30-120	8.28	10.94	1.36	0.12
A ₂	120-200	8.88	6.9	1.2	0.13

Profile No. YP6: Environmental and horizon description

Soil type: WRB (2006): Eutric Vertisols	Water table depth: Deep
Location: Adet, Upper Yazet	Moisture condition: slightly moist throughout
Date of description: 2-13-2014	Surface stoniness: None
Coordinate: 11 ⁰ 12'04.8''N37 ⁰ 35'5.7''E	Rock out crop: None
Elevation: 2331meter	Surface cracks: None
Topography: flat to gently slopping	Distance between cracks: None
Major landform: level plain	Land use/Vegetation: Cultivated land and Acacia, croton & Eucalyptus trees
Land element: None	Human influence: Ploughing
Position: lower	Flood frequency: None
Slope gradient: 3%	Evidence of erosion/deposition: Sheet & gully
Slope aspect & form: North	Degree & activity of deposition: None
Micro topography: None	Parent materials: Weathered
Effective soil depth: 200 cm	
Drainage Class: Moderately well drain	
Internal drainage: Not known	
External drainage: slow	

Ap 0-20cm very dark grayish brown (10YR 3/2), when moist; clay; firm when moist, very sticky and very plastic when wet; strong fine and medium angular blocky; common fine roots; common fine and medium pores; none calcareous.

A₁ 20-52 cm black (10YR 2/1), when moist; clay; firm when moist, very sticky and very plastic when wet; strong very coarse angular blocky; common distinct silken sides; few fine roots; few fine pores; none calcareous

A₂ 52-120 cm very dark gray (10YR 3/1), when moist; clay; friable when moist, very sticky and very plastic when wet; strong medium and coarse angular blocky; common distinct slickensides; very few and fine pores; none calcareous.

AC 120-200 cm very dark gray (10YR 3/1), when moist; clay; friable when moist, sticky and plastic when wet; moderate medium and coarse angular blocky; few distinct slickensides; very few fine pores; none calcareous.

Table 10. Analytical data for profile physical and chemical characteristics.

Horizon	Depth	pH	EC	Na	K	Ca	Mg	Sum
		H ₂ O	ds/m	cmol(+)/Kg ⁻¹				
Ap	0-20	6.3	0.127	0.09	0.95	20.03	3.84	24.9
A ₁	20-52	6.8	0.083	0.2	0.59	25.7	4.73	31.21
A ₂	52-120	6.7	0.088	0.3	0.69	24.71	4.72	30.43
AC	120-200	6.6	0.108	0.37	0.56	21.4	4.01	26.34

Horizon	Depth	CEC	Bas.Sa %	CEC/Clay
		cmol(+)/Kg ⁻¹		
Ap	0-20	37.72	66.01	1.78
A ₁	20-52	36.9	84.58	1.98
A ₂	52-120	45.02	67.59	1.62
AC	120-200	40.3	65.37	1.81

Horizon	Depth	T.N	O.C	C/N	Av.P.OI.
		cm	%	%	ppm
Ap	0-20	0.09	0.9	10.3	4.05
A ₁	20-52	0.02	0.3	14.06	0.76
A ₂	52-120	0.02	0.15	8.83	5.62
AC	120-200	0.01	0.09	7.11	5.89

Horizon	Depth	Fe	Mn	Zn	Cu
		cm	ppm	ppm	ppm
Ap	0-20	11.72	33.28	1.13	0.18
A ₁	20-52	6.78	7.64	0.51	0.14
A ₂	52-120	6.78	8.56	0.65	0.18
AC	120-200	5.86	11	0.71	0.27

Profile No. YP7: Environmental and horizon description

Soil type: WRB (2006): Eutric Leptosols	External drainage: well
Location: Adet, Upper Yezat	Water table depth: unknown
Date of description: 2-14-2014	Moisture condition: slightly moist up to 30cm
Coordinate: 11°11'11.9"N 37°32'9.6"E	Surface stoniness: None
Elevation: 2545meter	Rock out crop: None
Topography: Gently sloping to steep	Surface cracks: None
Major land form: Slopping land	Distance between cracks: None
Land element: None	Land use/Vegetation: Cultivated land & Acacia
Position: upper	Human influence: Ploughing
Slope gradient: 23%	Flood frequency: None
Slope aspect & form: South	Evidence of erosion/deposition: Sheet & rill
Micro topography: None	Degree & activity of deposition: None
Effective soil depth: 55 cm	Parent materials: Weathered
Drainage Class: Well drained	
Internal drainage: Never saturated	

Ap 0-15cm dark brown (7.5YR 3/2), when moist; clay; friable when moist, slightly sticky and slightly plastic when wet; moderate fine and medium sub angular blocky; many fine roots; common fine and medium pores; none calcareous.

A 15-25cm dark brown (7.5YR 3/4), when moist; clay; friable when moist, slightly sticky and slightly plastic when wet; moderate fine and medium sub angular blocky; common fine and medium roots; few fine and medium pores; none calcareous.

Table 11. Analytical data for profile physical and chemical characteristics.

Horizon	Depth	pH	EC	Na	K	Ca	Mg	Sum
		H ₂ O	ds/m	cmol(+)/Kg				
Ap	0-15	6.6	0.2	0.2	0.59	17.32	5.79	23.89
A	15-25	6.3	0.283	0.22	0.51	22.16	7.22	30.11

Horizon	Depth	CEC	Bas.Sa %	CEC/Clay
		cmol(+)/Kg ⁻¹		
Ap	0-15	41.68	57.33	1.03
A	15-25	38.36	78.49	1.28

Horizon	Depth	T.N	O.C	C/N	Av.P.Ol.
		cm	%	%	ppm
Ap	0-15	0.18	1.24	7.01	2.16
A	15-25	0.11	0.83	7.85	1.03

Horizon	Depth	Fe	Mn	Zn	Cu
		ppm	ppm	ppm	ppm
Ap	0-15	18.26	51.52	1.63	0.45
A	15-25	12.68	47.88	1	0.5

Table12. Analytical data for composite samples.

Field No	Depth (cm)	pH (H ₂ O)	EC (ds/m)	Sand	Silt	Clay	Textural Class
				%			
1	0-30	5.7	0.041	30	34	36	Clay loam
3	0-30	5.4	0.086	30	38	32	Clay loam
5	0-30	4.7	0.142	32	32	36	Clay loam
7	0-30	6	0.132	32	32	36	Clay loam
9	0-30	5	0.136	32	26	42	clay
11	0-30	4.8	0.092	22	22	56	clay
13	0-30	5.5	0.086	24	36	40	clay
15	0-30	5.3	0.084	22	28	50	clay
18	0-30	5.4	0.054	18	22	60	clay
20	0-30	5.7	0.129	22	32	46	clay
22	0-30	6	0.07	24	24	52	clay
24	0-30	5.7	0.075	24	22	54	clay
26	0-30	6.6	0.08	30	34	36	Clay loam
28	0-30	5.6	0.136	34	26	40	clay
30	0-30	5	0.1	19	28	53	clay
32	0-30	5.7	0.048	13	16	71	clay
33	0-30	5.8	0.072	19	22	59	clay
35	0-30	6.2	0.092	41	30	29	Clay loam
38	0-30	6.1	0.045	31	30	39	Clay loam
40	0-30	6.5	0.067	19	20	61	clay
42	0-30	6.4	0.056	39	36	25	Loam
44	0-30	6.3	0.064	25	34	41	clay
46	0-30	6.2	0.076	15	24	61	clay
48	0-30	6.3	0.055	21	36	43	clay
50	0-30	6.2	0.093	25	32	43	clay
53	0-30	6.2	0.091	19	14	67	clay
55	0-30	6.6	0.102	21	20	59	clay

Field No	Depth (cm)	pH (H₂O)	EC (ds/m)	Sand	Silt	Clay	Textural Class
57	0-30	6.1	0.096	31	14	55	clay
60	0-30	5.2	0.085	31	22	47	clay
62	0-30	6.4	0.074	17	20	63	clay
64	0-30	6.5	0.068	29	30	41	clay
66	0-30	5.5	0.103	19	20	61	clay
68	0-30	6	0.058	31	32	37	Clay loam
70	0-30	6.6	0.068	17	16	67	clay
72	0-30	6	0.047	19	24	57	clay
74	0-30	7	0.066	15	18	67	clay
76	0-30	6.9	0.08	19	24	57	clay
78	0-30	6.1	0.06	23	34	43	clay

Table12. Analytical data cont'd.

Field No	Na	K	Ca	Mg	Sum
cmol(+)/Kg					
1	0.11	0.19	24.15	6.09	30.54
3	0.13	0.36	20.37	3.05	23.91
5	0.15	0.18	8.89	1.93	11.16
7	0.33	1.06	18.77	4.13	24.29
9	0.09	0.29	12.24	2.96	15.58
11	0.11	0.24	8.96	2.19	11.5
13	0.07	0.18	20.67	4.86	25.78
15	0.13	0.19	16.54	4.16	21.02
18	0.11	0.37	16.92	3.56	20.96
20	0.15	0.58	20.87	5.43	27.02
22	0.13	0.78	22.81	6.56	30.28
24	0.28	0.18	23.36	5.08	28.9
26	0.3	0.49	29.31	10.82	40.92
28	0.2	0.37	25.18	7.99	33.74
30	0.07	0.36	13.5	2.7	16.62
32	0.13	0.5	18.12	5.42	24.17
33	0.11	0.36	34.53	8.17	43.17
35	0.17	0.59	27.2	9.42	37.38
38	0.13	0.42	32.02	8.9	41.47
40	0.2	0.54	45.02	9.93	55.68
42	0.22	0.23	29.43	9.61	39.49
44	0.22	0.33	42.56	11.18	54.3
46	0.22	0.47	28.39	7.97	37.05
48	0.2	0.88	31.68	9.62	42.38
50	0.28	1.57	30.02	11.52	43.4
53	0.26	1.09	25.11	7.35	33.81
55	0.22	0.61	26.39	8.77	36

Field No	Na	K	Ca	Mg	Sum
	cmol(+)/Kg				
57	0.17	1.46	17.93	4.3	23.86
60	0.11	0.99	6.18	3.69	10.96
62	0.22	0.69	25.1	7.82	33.83
64	0.15	0.56	27.3	11.65	39.66
66	0.04	0.84	9.61	5.12	15.61
68	0.13	0.54	16.97	5.84	23.48
70	0.2	0.73	26.19	8.07	35.19
72	0.15	0.61	21.72	6.63	29.12
74	0.26	0.77	35.72	9.16	45.9
76	0.28	0.99	30.24	10.6	42.11
78	0.17	0.61	13.49	4.93	19.21

Table12. Analytical data cont'd.

Field No	CEC cmol(+)/Kg	BS (%)	T.N	O.C	C/N
			%		
1	32.04	95.31	0.1	1.3	12.55
3	28.14	84.96	0.35	3.86	11.07
5	20.56	54.27	0.25	2.74	11
7	28.21	86.11	0.19	1.45	7.67
9	18.12	85.98	0.17	2.13	12.57
11	15.06	76.39	0.19	2.01	10.56
13	34.37	75	0.21	2.53	12.13
15	23.05	91.2	0.21	2.16	10.29
18	26.65	78.65	0.07	0.74	9.97
20	30.47	88.69	0.17	1.84	11.14
22	33.8	89.58	0.11	1.09	10.11
24	32.98	87.63	0.09	1.15	12.45
26	48.04	85.19	0.11	1.34	12.76
28	36.7	91.93	0.26	2.72	10.28
30	21.75	76.43	0.17	2.1	12.25
32	29.17	82.86	0.11	0.95	8.81
33	48.17	89.62	0.13	1.29	9.7
35	42.38	88.2	0.07	0.5	7.44
38	46.47	89.24	0.06	0.52	9.06
40	60.68	91.76	0.09	0.96	10.2
42	44.49	88.76	0.07	0.92	13.44
44	59.3	91.57	0.04	0.41	9.76
46	42.05	88.11	0.14	1.31	9.36
48	47.38	89.45	0.06	0.64	10.63
50	45.51	95.35	0.08	0.86	11.38
53	38.68	87.42	0.1	1.06	10.37
55	37.01	97.27	0.11	0.79	7.42

Field No	CEC cmol(+)/Kg	BS (%)	T.N	O.C	C/N
57	26.15	91.26	0.13	1.52	11.31
60	19.92	55.02	0.14	1.5	10.82
62	39.36	85.96	0.1	0.91	9.29
64	40.01	99.12	0.07	0.71	10.57
66	25.1	62.21	0.14	1.28	8.88
68	25.2	93.14	0.07	0.98	13.67
70	40.87	86.11	0.06	0.69	10.95
72	39.28	74.12	0.11	1.19	11.33
74	46.66	98.38	0.08	0.78	10.32
76	43.63	96.51	0.09	0.95	10.94
78	25.51	75.29	0.09	0.91	10.66

Table 13. Average Minimum Monthly Temperature in °C

Location : Adet Metrological station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2004	7.2	8.2	10.4	12.6	12.2	12.2	11.7	12.3	10.9	9.5	9.2	7.4
2005	6.1	8.8	10.8	13.2	11.6	11.6	11.7	12.3	12.0	11.2	7.8	4.7
2006	6.3	9.0	10.6	12.1	12.0	12.0	12.5	11.9	11.6	11.4	9.1	7.7
2007	7.0	7.8	10.4	11.0	12.9	13.4	12.8	0.0	11.4	9.7	8.8	6.6
2008	8.6	8.8	10.9	12.8	12.6	12.2	11.8	12.0	11.4	11.1	9.1	8.3
2009	7.9	10.9	11.8	11.9	12.4	12.5	12.5	12.6	10.9	10.8	8.0	8.4
2010	8.6	10.3	11.3	14.1	13.9	12.8	12.5	12.6	12.2	10.7	9.5	12.8
2011	10.0	11.7	12.2	17.8	18.1	18.1	14.6	13.0	11.7	10.7	9.4	12.8
Average temp.	7.7	9.4	11.1	13.2	13.2	13.1	12.5	10.8	11.5	10.6	8.9	8.6

Table 14. Average Maximum Monthly Temperature in °C

Location: Adet Metrological station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2004	27.2	28.1	29.8	28.7	29.7	25.4	23.4	23.0	23.8	24.4	25.4	26.2
2005	26.4	29.9	29.7	29.9	29.0	27.3	22.4	23.3	24.2	24.4	25.3	26.0
2006	27.5	29.5	29.7	29.8	27.5	25.8	23.2	22.8	23.8	25.1	25.3	25.7
2007	26.6	28.1	29.8	29.0	28.1	26.5	23.5	22.7	24.6	25.7	26.5	27.1
2008	27.4	28.3	30.2	27.6	26.3	25.2	23.4	23.7	25.2	25.1	25.6	27.1
2009	27.9	29.1	29.9	29.9	30.0	28.6	24.6	24.3	26.0	25.5	26.7	26.3
2010	27.3	28.9	29.7	29.8	27.9	26.4	23.4	23.6	25.2	26.0	26.5	25.9
2011	27.2	29.7	28.2	30.3	27.9	26.3	25.2	24.2	25.9	26.0	26.5	25.9
Av. Temp.	27.2	29.0	29.6	29.4	28.3	26.4	23.6	23.5	24.8	25.3	26.0	26.3

Table 15. Average Monthly Rainfall (mm)

Location: Adet Metrological station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2004	7.7	7	2	36.9	10.2	189.3	286.3	246.9	204	120.3	21.6	0
2005	1.7	0	27.9	40.4	0	105.1	331.6	213.6	192.6	135	27.4	0
2006	0	0.8	4.3	19	116.4	175	439.3	230	236.5	150.3	17.5	27.5
2007	3.5	1	14.1	19.7	94.3	271.9	313.8	275	137.7	60.2	27	0
2008	15.1	1	0	168.2	150.6	142.6	331.2	320	167.1	79.7	23.8	0
2009	0	10.9	34.7	32.6	46	100.7	297.7	281.5	124.9	80.2	7.3	15
2010	22.5	0	0	44.7	78.6	160	364.2	249.3	182.9	69.6	1.2	1.5
2011	21.5	0	23.9	70.5	161.6	83.6	338.7	213.6	155	69.5	1.2	1.5
Av. monthly Rainfall	8.3	4.1	17.8	54	94	153.5	337.9	253.7	175.1	95.6	15.9	11.4