UNIVERSITY of RWANDA

COLLEGE OF AGRICULTURE, ANIMAL SCIENCES AND VETERINARY MEDICINE

SCHOOL OF AGRICULTURE AND FOOD SCIENCE:

DEPARTMENT OF SOIL SCIENCE

MSc OFAGROFORESTRY AND SOIL MANAGEMENT

Msc AFSM DISSERTATION

TOPIC: SOIL SUITABILITY INVESTIGATION FOR LAND USE OPTIONS IN MBAZI SECTOR.

Presented by: Theophile HABIYAREMYE, UG: 217295495

Tel: 0788479060,
Email: theoshabis@gmail.com

Supervisor: Prof. Naramabuye François Xavier

Co-supervisor: Dr SIRIKARE N. Sylvere

BUSOGO, Octomber, 2019

ABSTRACT

Thisresearch wascarried out in the MbaziSector, Huye District, and Southern Province. The objectives of the study is to investigate the soil suitability for land use planning for agriculture. The investigation of the soil suitability was based on the soil properties information sourced from the Rwanda soil database and verified in the Research and Postgraduate Laboratory of Soil and Plants. The soil suitability investigation has a good impact on the crop production due to the selection of seed plantation according to soil suitable. The soil the study site has three different topographical features including,low land, middle land and up land. 24 soil samples were considered to verify some soil parameters including: organic carbon, bulk density, moisture content andexchangeable acidity, cation exchangeable capacity, soil texture,total nitrogen, electrical conductivity, available phosphorus soil pHinwater and KCl media. The soil in all topographical features is well drained with sandy loam as the dominant soil texture class.The value of bulk density values are: 1.38 g/cm^3, 1.44 g/cm^3 and1.66 g/cm^3 respectively from low land, middle land and upland. The soil reaction was strongly acid with pH ranging from 4.80 to 5.0. Low values of total nitrogen (TN)and organic carbon (OC) were recorded as well as very low values of available phosphorus in upland but for low and middle was medium this depend on an amendment. The soil moisture content for lowland (16.97%), middle land(9.24%) and upland (6.64%) were generally low. The electrical conductivityvalues were 0.029ds/m at 0-30 cm depth and 0.037ds/m) at 30-60 cm depth for low land. For middle land, values were of 0.015ds/m at 0-30 cm depth and 0.021ds/m)at 30-60 cm depth. For upland, the mean values were 0.038ds/m at 0-30 cm depth and 0.027ds/mat 30-60 cm depth. The soil texture was sand loam in low land and in B horizons of middleand upland. The texture of the top horizon for middle landand upland was loam sand. The exchangeable acidity and exchangeable aluminium are very high while the exchangeable bases are very low due to high acidity as demonstrated by low pH values.The computation of data has concluded that presently, the land was marginally suitable for proposed crops. However if land management and cropping systems were to be applied, some parameters including: moisture content, soil organic carbon, soil acidity, N-P-K, and base saturation can be improved and bust the land suitability.

DECLARATION

I, Theophile HABIYAREMYE, hereby declare that the work presented in this dissertation entitled“Soil suitability investigation for land use options in Mbazi sector” is my owner research. Ithas not been submitted for any degree in any other university or institution.

Date:…./09/2019

Theophile HABIYAREMYE, Registration Number: 217295495

Prof. Dr. Ir. François Xavier NARAMABUYE, Main supervisor

DEDICATION

To the almighty **GOD**

To our savior **Jesus Christ**

To my beloved mother
NYIRANTAMPUHWE Agathe.

To my beloved brothers

To my friends and my classmates

ACKNOWLEDGEMENT

It is my pleasure to address my sincere thanks to almighty **GOD** for having kept me alive before, and during my research project work and all time of my studies. Without GOD's blessings it would not have been possible to realize my research work.

My thanks are addressed to **CAVM** authorities and to the coordinator and teachers of the Masters program of Agroforestry and Soil management in particular for the knowledge I gained over the last two years.

I appreciate my **supervisor Prof. NARAMABUYEFrançois Xavier**, **Co-supervisor Dr. SIRIKARE N. Sylvere** who supported and guided this dissertation up to this stage.

Special thanks are conveyed to my mother and my family who have educated me. I will always recognize the love and support they provided to me.

To you brother and friends who have given me continuous good advice I am so thankful. Finally, let special thanks from my heart be addressed to my classmates, laboratory technicians with whom I passed two long wonderful years at UR.

May God bless all of you in your endeavors?

ACRONYMS AND ABREVIATIONS

SOM: Soil Organic Matter

BD: Bulk density

C: Carbon

FAO: Food and Agriculture Organization

CEC: Cation Exchange Capacity

CO_2: Carbon dioxide

Al: Aluminium

^{0}C: Degree celcius

C/N:Carbon to Nitrogen ratio.

EC:Electrical conductivity

%: percent

Ppm: parts per million

Ha: hectare

Cmol: centimols

dS: decisiemens

m.a.s.l: meter above sea level

FAO: Food and Agriculture Organization of the united nations.

K: Potassium

Mg: Magnesium

N: Nitrogen

Na: Sodium

pH: Potential of Hydrogen

Ca: Calcium

Contents

LIST OF FIGURES

LIST OF TABLES

CHAP.I. GENERAL INTRODUCTION

I.1. Background

Land degradation caused by land use is observed in many areas of Rwanda. Deforestation for timber products, firewood energy and cultivation are the main causes of soil degradation and environment destruction here in Rwanda(S. Keesstra et al., 2016). Soil erosion takes place on those deforested lands due to steep topography and removal of soil cover by agriculture practices(Ebabu et al., 2019).In addition to that, highland ecosystems are facing many problems including: acidification, erosion, deforestation(Mustafa et al., 2011). Soil erosion is accelerated by land degradation that caused the soil fertility to be reduced means the yield of crop plantations is small directly. The runoff and soil loss is littered with the farming activity as principal consequence (S. Keesstra et al., 2016). An over cultivation of soil, increase of bad situation in financial condition, response of economic opportunities as many human impact of land degradation (Pereira et al., 2017). erosion process caused the high risk in location space within the way of soil fertility lost, soil quality destroyed, soil production decline, biomass removed, once the flooding seem to the low land (S. D. Keesstra et al., 2017).

Studies are needed to assess soil parameters in the way of comprehend the extent of the problems and propose solutions. It is also important to measure some soil parameters on remediated lands so that one may understand the impacts of rehabilitation practices. This information could lead to proposal of better practices. Land suitability analysis is one of the most important, which can guide any rehabilitation process or land use option. According to Plan (2015), No study has been undertaken to assess the impacts of rehabilitation measures for the presentstudy area.It is proposed to conduct the land suitability measurement in the study area using Food Agriculture Organization Methodology. As reported by Sys et al., (1991), the land suitability allows a better planning of the land use option. In the present case, different crops will be assessed for suitability and a ranking of the best suitable crops will be proposed. As proposed by Berka (2005), limitations of different land units will guide the types of land management to be proposed. Therefore this study aim to carry out soil suitability analysis for land uses option in Mbazi sector**.**

I.2. Problem statement

The land use concentration inthis area has been more and more rising thanks to deforestation for timber, andover cultivation on side as a result of low land will we have, this could cause terrible downside in environment like soil erosion, flooding in lowland, eutrophication method in main stream then on. This modifies to end in severe deterioration of soil fertility(Nakao et al., 2017).Here in Rwanda there are several mountain and enormous quantity of precipitation which may cause many issues like runoff, soil erosion, low soil fertility and land productivity decline, reduction of crop yield and food insecurity(W. Wei et al., 2016).Those are caused by deforestation and over cultivation on high slope and choice of seed selection while not reckoning on soil quality or suitability analysis. Therefore, this study was initiated to analyze within the application soil quality analysis for land use through agricultural practices and environmental conservation. it's many roles in civilizing environmental price, like these follows decrease runoff and defend water, manage erosion of soil and profit the conservation of soil, develop soil fertility and land productivity, augment crop yield and increase food security and advantage restoration of vegetation and develop diversity, and create aesthetic landscapes and enhance recreation (W. Wei et al., 2016).

I.3. Objectives

I.3.1. Main objective

- Soil suitability development for agricultural production inMbazi sector.

I.3.2. Specific objective

- Review of soil physical and chemical properties to be used in soil suitability development.
- Verification of some soil parameters in laboratory to increase accuracy of data.
- Evaluation of the suitability of soil for various types of crops: coffee, cassava, bananas, beans, sorghum and maize.

I.3.3. Research Questions

- What are the actual soil statuses with regard to specific parameters?
- What are the categories of land suitability inMbazi sector?
- What types of land management could improve the land suitability of the studied site?

Concept framework

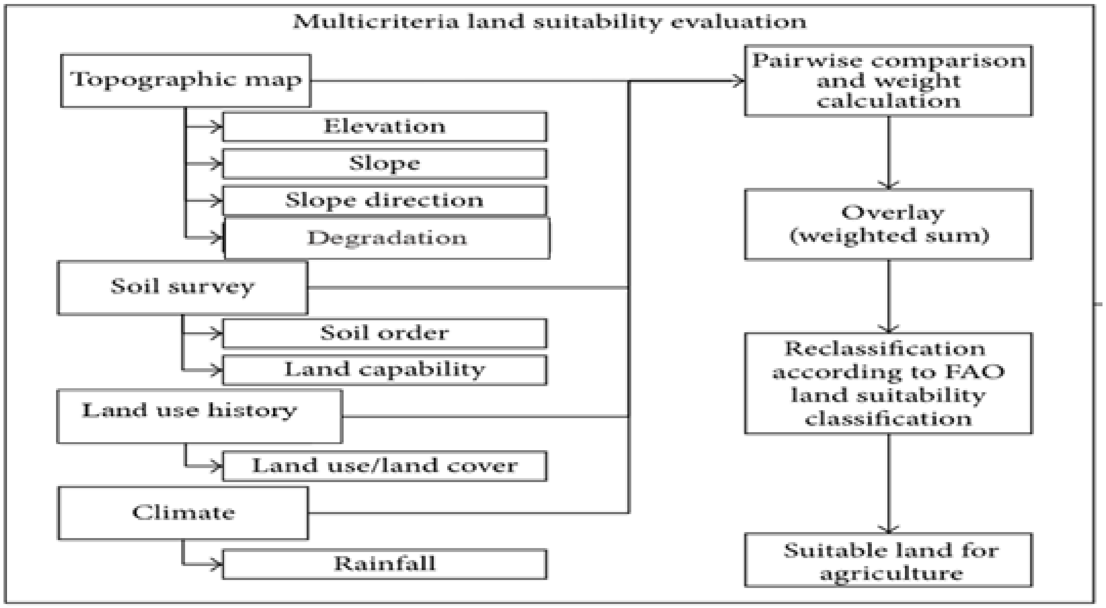


Figure 1 :Flowchart for land suitability(Amiri et al., 2013).

CHAP.II. LITERATURE REVIEW

II.1. Introduction

This chapter highlights the relationship between the present study and the work done by other researchers in similar areas. In this review, general and relevant concepts will be reviewed. The following areas will be focused on: (1) Land suitability analysis and land use analysis, (2) Suitable criteria for land use, (3) Crop requirement and soil characteristics, (4) Land use Requirement for Selected Crops Grown, (5) Soil erosion, (6) Soil erosion comprehensively defined. Important definitions allowing the understanding of the subjects are outlined. Work done on similar topics will be emphasized to guide the reader of this work. In general reason of this review is to recognize the concerning of results of studies linked to topic under study.

II.2. Land suitability and land use analysis

Soil suitability evolution exacting utilizes multifaceted procedure which participates in much decision which relate to socio-economic, biophysical and institutional aspects. Analysis of soil suitability has a structured and approach that is very essential(Mcdowell et al., 2018). The success of crop is based on the following factor such biotic, socio-economic and abiotic. The productivity of crop is determined by biotic, a biotic and socio-economic all are based on the FAO structure of land assessment which is developed from previous land capability approaches(Akpoti et al., 2019).In all-purpose land suitability of a land use is evaluated from a set of self-determining soil qualities, which may limit the land use potential. These evaluations categorize plot units of natural resource inventories, means that legend categories of soil analysis are classified into fitness subclasses, based on the numeral and brutality of limits to land use (Prakash, 2003). Suitability of land categorization is organized planning of dissimilar kinds of land according the following properties like (inherent soil properties and external land features) that decide the ability of land. The qualitative assessment of land suitability for differentuses based on economics, social and biophysical criteria (Verdoodt et al., 2003)

II.3. Suitable criteria for land use

The majority plant variety want well drained; moderate fine to medium texture soils, freed from salinity and having most favorable physical location. Soil reserve maps supported many parameters, will help in predicting the behavior and suitableness of soil accordingly to the crop growing in the field, forest species, crops agriculture and also crop plantation alternatively for the suitableness criteria which is recognized(Mishra,2016).The land quality classification for FAO has complete four dissimilar categories such as Order, class, subclass and Unit(Mishra, 2016).

The soil site parameters thought about for the aim of evaluating land, farming, forestry, for plantation crops and for delineation suitableness categories are: soil site characteristics connected soil quality weather as moisture availability, resistance to erosion process (topography and Landscape) and moisture accessibility, flooding, drainage these are humidity environment. Soil texture, availability of water, gravels/stoniness, accessibility of foot hold for surface and subsoil, root growth all are included in physical conditions and growth root(deepness, accessibility of hold foot for plant, availability of nutrient, calcium carbonate, nutrient deliver, and gypsum), Not promptly correctable organic matter(O.M), Cation Exchange Capacity (CEC), base saturation, nutrient available, salinity and alkalinity and ground water and dept all are soil fertility (Mishra, 2016).

II.4. Crop requirement and soil characteristics

The original step of preparation the future agricultures land use is based on the link between crop requirements and soil characteristics. The objective of the study is to categorize the potentials and constraints of the key soils, assess them for crop fitness sand suggests farming of land use plan at village level. Soil texture, hydraulic conductivity, water holding capacity, soil pH, depth of soils, SOC and also properties of intrinsically are based on soil analysis(Vasu et al., 2018). Intensive agriculture contributes to the food production, but the constraints for new crops are soil suitability problem. For evaluating soil we depend on crops suitability, physical and chemical properties (Dalanda et al., 2016). Soil and plant uniqueness is microbial patterns of the trends and influencing the factor of grassland chain with no disturbance of human being remains indefinite(Zhao et al., 2019).

II.5. Land use Requirement for Selected Crops Grown

II.5.1. Maize crop (Zea mays L.)

Maize grows on a large vary of rain patterns in East Africa(Norman et al., 1984).It is a drought sensitive crop, which needs 750 to 1250 mm of well distributed precipitation throughout the season (Young, 1976). It's to be fully grown fully daylight for efficient photosynthesis (Du

Plessis et al., 2003). Themost favorabletemperaturefor maize growth and plant development are 18 to 32 °C. The foremostfavorable soil wetness content for plant growth and development and for top grainyield is 60 – 70% of volume unit (Sowunmi et al., 2010). The majority soil appropriate for maize is for maize isindividualwith smart usefuldepth,positivemorphological properties, smart interior drain enough and balanced quantities nutrients of cropsthat arefavourable specifically for the yields of maize (Euroconsult, 1989). Effective soil depth of over 100 cm, well drained, fine structured soils that are made in Organic matter are rated appropriate (Raemaekers, 2001). Sandy and shallow soils depress yields each thanks to it will increase drought hazard and low nutrient supplies(Young, 1976).

The pH $_{\text{water}}$ for low input farming level 6.0 - 7.0 is rated appropriate whereas but 5.5 and on top of 8.0 is rated marginal (FAO, 1988). Oxisols, Ultisols, Alfisols and Inceptisols are proverbial to own greatest potential for maize production within the tropics (Norman et al., 1984). However, maize production within the acid and extremely weather-beaten soils is often restricted by nutrients deficiencies. Maize suffers severe depression of yields on poor soils primarily N as a result of it's one of the foremost nutrient hard to please crop (Young, 1976). The bare regions are mainly fitted for cultivation of maize crop; as a result of this method help us to use the machine in the agricultural activity. Even if, maize is additionally crop cultivation on swelling land likewise as on down hills which has lower slope. Maize as crop is additionally adult as a serious shifting cultivation crops (Du Plessis et al., 2003).

II.5.2. Beans crop (Phaseolus vulgaris L.)

Common bean grows healthy in the regions which have medium precipitation. Too much rain and hot conditions cause flower, pod drop and augment the frequency of diseases (Raemaekers, 2001). The optimums temperatures for seed germination vary between 25 ^{0}C and 30 ^{0}C (Raemaekers, 2001). Germination needs a soil temperature of 15 ^{0}C or additional, and at 18 ^{0}C germination takes regarding 12 days, whereas at 25 ^{0}C regarding 7 days(Faostat, 2001).The crop doesn't have specific soil needs however friable, profound soils with pH scale of 6.0 to 7.5 are most well-liked. Common beans are known to grow with success on a moderately wide selection of soil textures ranging from light sands to heavy clays Common bean is sensitive to soil salinity and it's additionally a drought sensitive crop therefore it is not appropriate to sandy soils in areas of marginal precipitation (Young, 1976). The soil ought to have high offered water capability as a result of the crop prefers wet soil throughout the season (Norman et al., 1984).

II.5.3. Coffee (Coffea Arabica)

Coffee could be a plantation crop well tailored to completely different eco-physiological conditions of the tropics. coffee is customized to cooler temperatures of the tropical highlands higher than 1000 m altitude on the equator; somewhat lower at larger latitude(Pohlan, 2009).The suitable temperatures vary for occasional is 12 °C to 26 °C, precipitation is regarding 1500 mm a year, and soil sort is sandy-loam. It can do best in any fertile soil, the coffee needs deep pervious soil, of fine structure, high organic matter and favorable water balance(Guideline, 2012).

Soils below agricultural of coffee systems are characterized by terribly pH which is very low scale value (< 5) with high Aluminium toxicity in soil ($> 30\%$), terrible lower Ca ($< 30\%$), Mg ($< 10\%$), Nitrogen ($< 0.16\%$), Phosphorus (< 20ppm), potassium ($<5.8\%$), sulphur (< 20ppm), Zn (< 1ppm), and Bo(<0.8ppm). Ca and Mg element deficiencies are universal in agricultural coffee systems all through the country thanks to high Al toxicity in acid soils(Nzeyimana,2013).

II.5.4. Sorghum (Sorghum bicolor)

Sorghum is associate native crop to Africa, and though industrial desires and uses could modification over time, sorghum can stay a basic staple food for several rural communities(Sorghum et al.,1994).Sorghum is generally full-grown in associate annual rain vary of 300 to 750mm.Near the beginning droughts top to floral opening and also the vegetative plant remains(West, 2009).The soils of sorghum crop needs are lower; it produces sensible production on lightweight and extremely light soils. It performs most excellent on a little acidic soil. Sorghum became mature in places wherever weather situation areas well dry and very warm for maize. Sorghum grows on each sandy soil and on significant and clay soil, at H^+ concentration varies from 5.0 to 8.5. It's extremely proof against soil salinity and may conjointly grow on soils with low permeableness. It grows alright on lightweight which is heat as well and fertile(Prażak, 2016).The required for optimum growth of sorghum, temperature may be a vary of 20 to 30 ºC(Sorghum et al., 1994).

II.5.5. Bananas (Musa acuminata)

Banana as plant could be massive perennial crop with leaf heath that type stem like pseudostems. The banana plant has eight - twelve leaves which are up to 270 cm long and sixty cm large(Nutrient al., 1996).Bananas need a heat, moist, frost- free typical weather with most favorable temperatures along with22^{0}C and 31^{0}C. The plant burgeon beneath consistently consider warm conditions. The growth of shoot is greatest between 26 and 28 ^{0}C and growth of fruit range is 29 and 30^{0}C.The plant growth under16^{0}C, is slowly but for 10 ^{0}C is stopped. The temperatures below -2^{0}Cmight destroy plants to ground level. Though, new growth naturally sprouts from underground stem with heat conditions. Temperature at top of 37 ^{0}C might lead to burn and rising leaves new might have terribly slight blades. Banana crop do best on slope of (0-1%),deeper soil, well drained soil, and organic matter is highly needed (Production, Centre, Agricultural, & Services, 2008).Bananas want wealthy, wetness and well soil drained with 40% clayey soil, silt soil 75%, loam soil85%.Banana crop like acidic soil with pH 6-7.5.Thelowest PH of soil makes banana a lot of at risk of Panama malady. Light weight soil sandy may be improved by inserting the mulching practice where the banana crop is planted. This can improve the retention of water and forest, all nutrients from percolating rapidly in to the soils. The soil deficient nutritionally is enhanced by incorporating the organic matter related to the soil before you plant your Banana crop then mulches them densely. Method ought to be continual usually attainable. Banana plant don't tolerate the work of water as a result of its roots can rot(Background et al., 2013).

Banana need superabundant rain concerning 1200 and 2000 manually(Wairegi et al., 2015).

II.5.6. Cassava (Manihot esculenta Crantz)

Cassava may be a little perennial ligneous plant, typically 2−3 m tall, that produces thickened roots that are largely full of starch. This crop is wide mature in tropical and subtropic countries in Latin America, Africa, and Asia; Cassava is one among the foremost necessary food crops in several countries in sub-Saharan Africa(Howeler, 2014).In common, the crop wants a warm, wet weather. Temperature is very essential, as all growth stop at regarding 10^{0}C. the most excellent tuber production will be expected within the lowlands of tropical, associated below altitude of 1500, wherever average temperatures 25^{0}C and 29^{0}C, however a few varieties grow at altitudes of up to 1500 m(Department of Agriculture, 2010).Optimizing rain fed cassava production needs careful attention to planting dates, planting strategies and planting positions and soil management practices that facilitate to conserve water. Though it will grow in areas with 400mm of rain a year, most root yields in Kingdom of Thailand were correlative with rain totaling regarding 1 700 mm (To & Production, 2013).cassava crop grows fine stone light weight, loamy sand or sand loamy that are damp, fertile and deeper, however, it is additionally well on soil go to the texture from sand to clay soil and comparatively low fertility (Department of Agriculture &Fisheries, 2010).

II.6. Soil erosion

Soil erosion could be a advanced method which the soil mineral materials it causes them to be lost, along with soil organic carbon (S. Wei et al., 2017). Place you have got vary of bulk density of 0.6–0.8 mg/m3 and rigorous in encompassing space of soil surface, SOM is preferentially removed by wind and water erosion(Lal, 2018).The biological and engineering methods such as hedgerows, trenches, bench terraces or progressive terraces and soon those associated with soil losses (Adimassu et al., 2017). The method used for site mitigation incorporates soil management and agronomic measures like mulching contour cropping and reduced tillage(Rutebuka et al., 2019).

II.7. Permeability

The permeability of Soils has the interrelated voids which participate in the way of allowing the movement of fluids is started from energy of higher to the energy of lower of the place. It is calculated due to the seepage under hydraulic structure and water quantities during dewatering activities(Elhakim,2016).

II.8. Soil depth

Soil depth involve in soil microbes, plant roots and for soil Nitrogen. The depth of soil is vertical factor which access the physicochemical and microbial properties due to the use of land, farmland, orchard, grassland and forsaken land(Liu et al., 2017). The depth of soil profile is up to 1m, this is based on land use like grassland, forest land, terraced land, and sloped cropland(Cheng et al., 2018).The physical soil properties and growth of root associated with available water and carbon stocks of soil, those were assessed in soil profile means that the development of root system referring to the density of root and length root this is necessary for water pumping from under the soil and help crop to be stable(Vale et al., 2019).

II.8. Soil pH

Main indicator of soil quality is pH of soil. Soil pH has a big function in process of soil like solubility and nutrient accessibility to the plant, in activity of microbes' soil organic matter decomposition, contaminants sorption and in biogeochemical cycles. Master variable of soil chemistry is soil pH in the way of controlling the reaction in soil. Liming and requirements of fertilizer in farming fields is based on soil pH. Soil Ph acting a big function in the soil weathering process and minerals variation(Kome et al., 2018). Soil pH has influence on plants growth and sorption in soils(Fornasier & Di, 2018)

II.9. Soil Texture

The size of soil particles defines soil texture. Those particles classified for large, small, or middle size. Soil particle size is divided by the conventional method of characteristics of range size recognized as fractions of textural such as sand, silt and clay. Soil with coarse particles is sandy; when it has fine particles it is named clay and if there is more or less equilibrium combination, this soil is a loam(Hillel,2003).Texture soil is normally used for properties of soil in agricultural sciences, hydrology, fields water balance as components, soil aerations, availability of nutrient, and soil texture as essential parameter control the influence of land capability and soil quality(Vasava et al., 2019). Additional, soil of sandy tender facility of crop growing, root and root harvesting and also crop tuber(Vladimir et al., 2019)

II.10. Total Nitrogen

Nitrogen is main element has function in soils. Low production and water pollution are caused by the soil loss and its nutrient. Land use changes consequential the impact of total nitrogen in soil from anthropogenic disorder and climate change. Wrong management of soil structure for land use can direct to the erosion of grave soil and soil nutrient defeat with runoff on surface (Xu et al., 2017). Essential element in the critical zone is soil total nitrogen. A key role by disturbing soil properties, plant growth, and microbial activities in ecosystem is soil total nitrogen(Qiao, Zhu, Jia, & Huang, 2018). SOC and STN can be influenced by Nitrogen fertilization under perennial grasses (Sainju et al., 2017)

II.11. Exchangeable Aluminum

Aluminum is powerfully metal hydrolyzing metal and its pH determined in chemistry. The presence of certain complexing ligands and acidic conditions increase the solubility of aluminum. Al reduces the rate root growth or damage it and also cause the reduction quantity of Ca, Mg and P(Chen et al., 2018). An alumino- silicate minerals as crystalline in soils is aluminium comparatively opposed to disbanding yet severe situation widespread in soil acidity(Yvanes et al., 2014).Al exist in dissimilar forms in the soil such as gibbsite and kaolinite, Al contribute incomplexation reactions with soil organic matter(Gu et al., 2017).

II.12. Cation Exchangeable Capacity

CEC (Cation Exchange Capacity) is the soil capacity of holding the nutrients. The important values in reclamation and land drainage of ground water pollution are based on the knowledge about CEC. For the land of farming, CEC involves in the availability of nutrient, soil stability, soil pH, participating to against soil acidification. Fertility of soil, retention capacity of nutrient, and groundwater protection are measured by CEC(Shiri et al., 2017).Clay minerals and organic matter associate with cations on its negative charges (Liddicoat et al., 2018).CEC of soil and soil stabilized cement and strength has connection between them(Yu et al., 2015).

II.13. Soil Organic Matter

SOM (Soil Organic Matter) formation is the main foundation material from Plant biomass. Conservation tillage has function of maintenance the crop residue or organic materials in the way of providing soil cover. Crop residue which is used for management ecological impact assessment, show larger quantity of crop residues remained in the fields led to improve the health of soil, reduce soil erosion and increase crop residualas organic in soil(Caricasoleet al., 2018)

II.14. Climate

The impact of climate in soil formation is largely due to precipitation and temperature variables (Brady and Weil, 2002). Precipitation is natural phenomenon used to get amount of water need for minerals weathering, movement of minerals and releasing elements while temperature of soil based on the rate of chemical. The climate is characterized by two seasons such as dry season and rainy season. For the temperate region the results of cold air come from in to the zone are the rains (Dalanda et al., 2016).

II.15. Topography

Topography control soil spatial patterns for land use at exacting site. Topography is key factor which influences the variation of property of soil through the effect of runoff, drainage, micro climate and soil erosion. There is not direct consequence of topography on denitrification process in soil in riparian areas which is very weakly understood (Xiong et al., 2015). Topography also describes difference in elevation where soil loss is general encouraged by steep slope through the erosion process and allow less amount of rain fall to penetrate into the soil before running off. The rate of water flow on soil is influenced by slope shape or length. Lastly in temperate and moisture (Brady and Weil, 2002).

CHAP.III. MATERIALS AND METHODS

III.1. Introduction

This chapter shows in details how research was carried out. It briefly describes the method, materials, techniques and approaches used during the research process. It also describes the research design, population, sample size selection, and data collection, processing, data analysis and the description of research site. The study will select the specific methodology based on its specific objectives and suitable for finding soil suitability analysis for land use optionsin the Mbazi sector.

The activities will be conducted in Southern Agriculture Zone/ Huye district at Mbazi sector.

III.3. Geographical situation

Huye district is central plateau. The topography of it normally is hilly in southern part, between $46^0$67 93'E and 47^0 18 213'N, 46^0 68 45'E and $47^0$18 129' N for lower land, 46^0 68 19'E and $47^0$18 365'N and 46^0 68 54'E and $47^0$18 326'N for middle land, 46^0 69 73'E and $47^0$18 402'N and 46^0 68 68'E and $47^0$18 390' N for upper land. Average altitude of hills is 1700 m but altitude of marshlands area is 1650 meters(Plan 2007).

III.4. Climate

In Huye District there is temperate climate. The temperatures is approximately 20^0C, the annual rainfall is 1160 mm. here there are 4 climatic seasons like extended period of rains from middle of February to; extended dry period from June to middle September; small rainy period from middle September to December and little dry season from January to middle of February(Plan 2007)..

III.5. Soil

On the mountain depth of soil depend on the parent material. These soils are sandy, has enough humus if the soils are not formed on mountain where erosion occurs. Dorsal granite form the soil which is not fertile means that they have low humus content. At any time soil erosion is not occur the koalisol type of soil become fertile(Plan 2007).

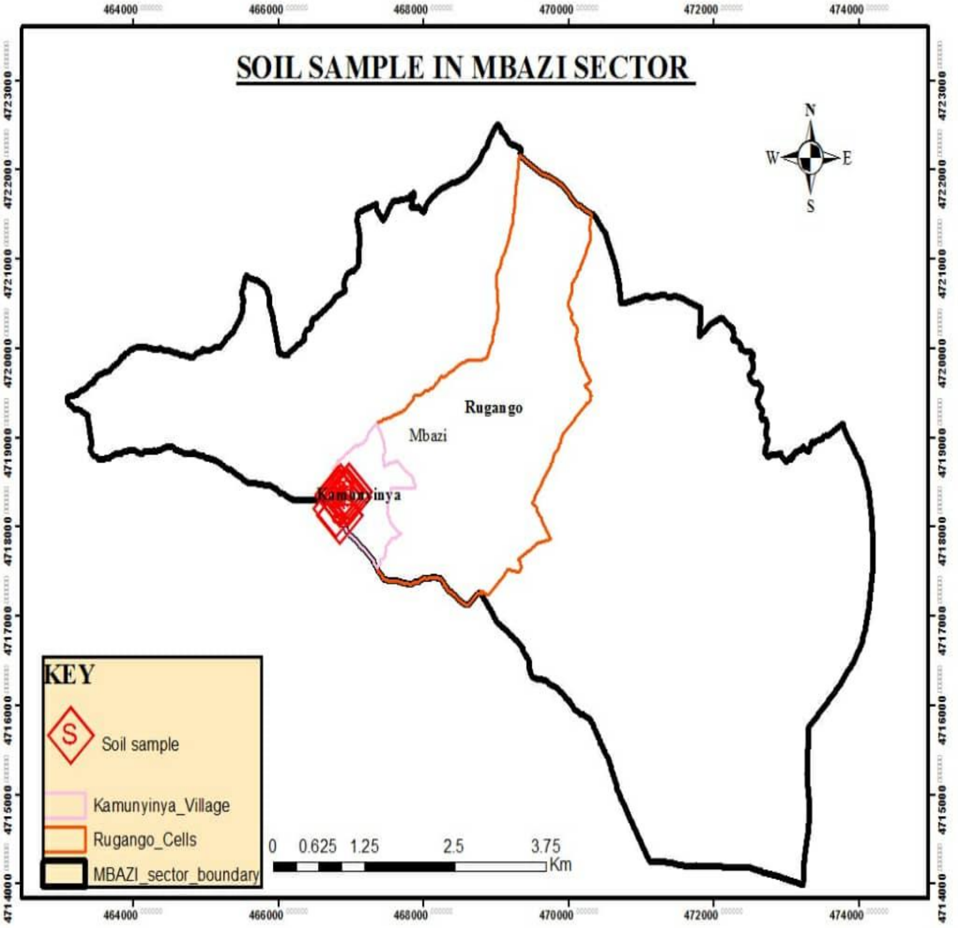


Figure 2: Map Mbazi sector (Study Area)

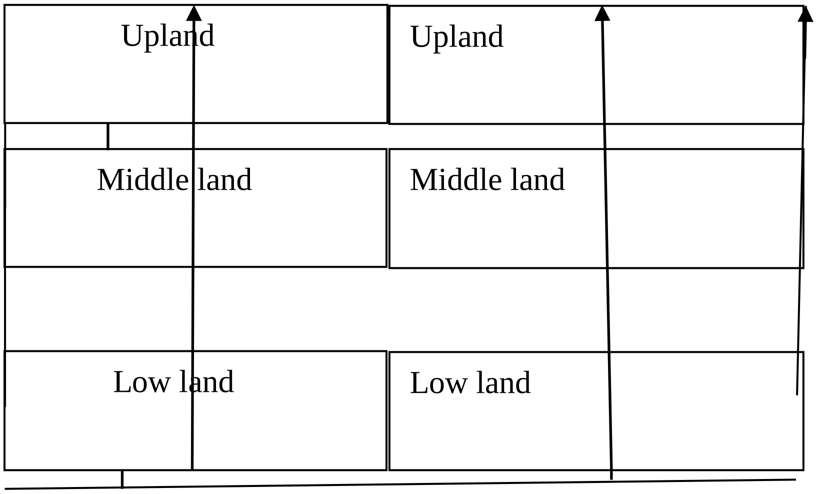
III.6. Physiography

The district of Huye is located in the central plateau of Rwanda. Topographically, this district is characterized by hilly landscape, from east to west and develops into a steep hills and mountainous area as one move, towards the north and west. The average altitude of hills are 1700m.a.s.l. and decreases to 1450m.a.s.l.For the western part of the district there are high rising and falling well as the well-known Huye Mountain which has an altitude of more than 2000 m.a.s.l (Huye District, 2012).

III.7. Soil sampling

The study site was splited into three sub sites: low land, middle land and upland. The subdivision of those sub-sites was mainly based on: topography, slope, soil cover and altitude. In each sub-site, two vertical transect were considered and 4 composite samples were collected for each transect. 8 composites samples were then sampled in each of the three sub-sites which made it a total of 24 samples per horizon (top soil and sub soil). It is important to mention that Y sampling method was applied for each composite sample. Both top soils (0-30 cm) and sub-soil (30-60cm) samples were collected. Field information was also recorded.

III.8. Sampling design



The soil samples were brought to the UR-CAVM-Research and Postgraduate Laboratory of Soil and Plant for analysis. The parameters analyzed included: Texture, soil pH, Electrical conductivity, Bulk density, and Exchangeable Aluminium, Exchangeable Acidity, Organic C, total Nitrogen, available Phosphorus, and CEC (Cation Exchangeable Capacity).

III.9. Materials for data collection.

III.9.1. Field materials

Clinometer, Tape, Soil auger, Rainfall simulator, Envelopes (plastic boxes), Marker pen.

III.9.2.Laboratory Materials

Balance, Stirrer, Sieved sieves, Reagents, mechanical shaker, Flasks, Beakers, Erlenmeyer, Thermometer, Graduated cylinder, Furnace machine, Oven machine, AAS, U.V-visible.

III.10.Methodology

III.10. 1.Soil Texture analysis

SOIL particle size was determined by hydrometer method after dispersion with sodium hexametaphosphate 5 %(NSS, 1990), and textural classes were determined using the USDA TEXTURAL class triangle (USDA, 1975).Weigh 50gr of dry soil, pass through of 2mm, in a beaker of 1 liter, add 5ml of hydrogen peroxide 30% and 150 ml distilled water, Heat then the suspension in a sandy bath at 90^0c to destroy organic matter till complete disappearing of gazes production while the heating. Let cool and transfer the suspension into a high speed stirrer cup and add 50 ml of sodium hexametaphosphate 10%.After stilling transfer the suspension into a 1000ml cylinder and fill up to the mark with H_2O distilled. Mix well suspension or by several reversal of the cylinder to put the soil in suspension. Put down the cylinder on a flat surface and note the time. Place immediately on hydrometer in the cylinder and let it stabilize. Proceed to the first reading at 40 seconds. Take also the temperature on that time. Then let stand for 3 hours and proceed to the second reading with the hydrometer and temperature. First reading is a value of silt and clay in solution, second reading correspond to the value of clay in soil solution Calculation:% sand = (50 g/l –first reading value) ×100, % Clay= (second reading value: 50g/l) ×100, % silt =100-(%sand+ % clay).

III.11.Soil depth determine

Soil depth as determine because it had a function in the estimations of productivity potential and erosion, normal landscape and geographical variation and help us to know the place of rock positions for depth. It helped to know the soil depth at non-cultivated sites or varying landscape positions. Here used field equipment for digging soil in the way of making the soil profile.

III.12.Soil reaction (soil pH) determination

III.12.1Soil PH (Water and k Cl)

Soil pH was measured Potentiometrically in water and in 1N KCl at ratio of 1:2.5 soils: H_2O (water) and KCl (Okalebo, 2002). I weighed 10g soil sample sieved in 2 mm.I added 25ml ofH_2O distilled and stir mixture for 10 minutes, allow standing for 30 min and stirring again 2minutes.Measured pH of soil suspension. Then read them to the PH meter. The processes were the same both on KCl and H_2O measures.

III.13.Soil organic matter determination

Soil Organic carbon was determined using the Walkely and blank wet oxidation method (Nelson and Sommers, 1982) and organic carbon was converted to organic matter by using 1.724 as a conversion factor (Dursma and Dawson).I introduced into an erlenmeyer of 250 ml 0.3g of dry soil ,ground to pass on 0.5 mm, I added 10ml of $k_2Cr_2O_7$ and agitate smoothly, I added 20 ml of H_2SO_4 96% and agitate vigorously during 1 minute and 30 minutes of standing, I added 100 ml of distilled H_2O, I added 10 ml of phosphoric acid and allow cooling, I added 2ml of indicator solution and titrate with ferrous sulphate while the mixture is being stirrer. At the end point the brown color becomes purple or violet and titration must be slow down. At the final end point of titration the color changed from sharply to green.

Table 1: organic matter and organic carbon levels and their interpretation are the following

Level of organic Matter %(g/100g)	Level of organic carbon %(g/100g)	Rating	Interpretation
<0.70	<0.40	Extremely Low	Subsoil’s or severely eroded, degraded surface
0.70–1.00	0.40–0.60	Very Low	Very poor structural condition, very low Structural stability.
1.00–1.70	0.60–1.00	Low	Poor to moderate structural condition, low to moderate structural stability.
1.70–3.00	1.00–1.80	Moderate	Average structural condition, average Structural stability.
3.00–5.15	1.80–3.00	High	Good structural condition, high structural stability.
>5.15	>5.15	Very high	Good structural condition, high structural stability and soils probably water repellent.

Organic carbon stocks are extremely prone to human activities. They decrease considerably (and sometimes rapidly) in response to changes in land cowl and land cover like deforestation, urban development and inflated tillage, and as results of unsustainable agricultural and forestry practices (UNEP, 2012). In line with Mutwewingabo and Rutunga,1987 the soils have low average price of total organic carbon all told investigated since they're belong within the vary of 0.5-1.5%. However, the soil organic carbon furthermore as soil organic matter is very considerably affected by soil tillage and organic modification. The level of organic matter and organic is bigger in lower land than upper land and middle land, because this space occupied by some sediment from higher land, that contain some organic residue. The organic matter represent for this totally different geographic feature(lower land, middle land and up land) with the typical values of 36.76 you look after lower land , 35.07 you look after middle land and 28.16 % for higher land severally . This lower quantity of organic matter content is that the results of high decomposition, few amount of organic change in soil and thanks to over cultivation effects that create organic matter content to be modify quickly.

III.14.Soil fertility (CEC) determination

Cation Exchangeable Capacity based on Saturation of soil with neutral 1M NH4OAc, adsorbed NH4$^+$displacedby 1MKCl (Okaleboet al.,2002).I weighed 5g of dry soil sieved at 2mm put it on a funnel with a filter paper above a 100ml plastic bottle, I added 100ml of 1N NH_4 acetate pH 7 in portions of 25 ml four times, I collected the leachate into the flask and keep it for exchangeable bases analysis using Atomic absorption spectrophotometer (AAS),I washed the sample with 100ml of ethanol 95% (use 4 portions of 25 ml) to remove excess ammonia, Lastly leach the residue on filter paper with 100 ml of 1 N KCl using 4 portions of 25 ml, I Pipetted10ml of the leachate into distillation tube and add10ml of 40 % NaOH, I Prepared the receiver by pipetting 5 ml of ascorbic acid 1% containing drops of mixed indicator, I distilled the sample until the distillate is about 100 ml, then titrate the sample with standard acid 0.1 N HCl, I Calculated the CEC by using the following formula: CEC (meq/ 100g of soil) $=\frac{(S-B)\times 1000\times NHCl\times 100\times 100}{Wt\times 10\times 1000}$, Where 5g is used then the equation becomes = (S-B)*NHCl *200Where: Wt: weigh of sample, S: titre of sample, B: title of blank, N: Normal acidity, 1000: ml to a titre, 10: volume of sample taken, 100: 100g of soil

III.15.Available phosphorous (we will use Bray 2 method)

Available phosphorus was determined using Bray no 2 methods due to the soil pH values which were low showing that the soil was acidic. This method was done in two steps, the first step was extraction from the soil using Bray extracting solution and the extracted phosphorus was measured using colorimetric determination (Okalebo, 2002). In summary, added2.5g of dry air soil sieved on 2 mm into plastic bottle of 250 ml, added 50ml of the bray P2extracting solution and shake for 5 minutes, then filter them trough whatman. After Pipettes 10 ml of every P standard series solutions, took also 10ml of each soil extract and 10ml for the blanks into 50 ml volumetric flasks, filled it from 1to the 50ml mark with distilled water. Stop and shake content well. After one hour, using a spectrophotometer or colorimeter for reading the absorbancy on it. Then use this formula in Calculation: P (Mg.Kg^{-1}) =$\frac{(\mathbf{a}-\mathbf{b})\ \times v\times f\times 1000}{1000\times w}$, a= concentration sample

b= Blank concentration= weight of soil, f= dilution factor

III.16.Total nitrogen: Colorimetric determination of Total Nitrogen

TN was determined by digestion using an electrical hot plate in a fume hood and colorimetric determination (Okalebo, 2002). The content of total nitrogen was measured in a digest obtained by treating soil sample with hydrogen peroxide, sulphuric acid, selenium and salicylic acid. Briefly, 0.5 gr of soil sample ground to pass in 0.5 mm were taken and put in a mineralization tube and add 1.5 gr of catalyst and add 10 ml of H_2SO_4 concentrated mineralize until a green color appears, allow cooling and transverse in a volumetric flask of 100 ml and carry to the mark with distilled water. I diluted the entire digest to a ratio of 1:9 with distilled water and with the micropipette I took 0.2 ml of digest into a clear test tube and add 5.0 ml of the reagent N1 and 5.0 ml of reagent N2 and vortex allow to stand for 2 hours for the full green color development and measure the absorbance at 650 nm on UV spectrophotometer. Then calculated with this formula: N %={(a-b) ×v×100×50}/ (1000×w×al×1000), Where a = concentration of N in the solution, **b** = concentration of N in the blank**, V**= total volume at the end of analysis procedure, w = weight of the dried sample and **al** = aliquot of the solution taken

III.18.Parent material determination

Parent material determination was the ways of knowing the type of minerals you had got on site. Means that determination of parent material in the fields was help to know the minerals which occupied this site.

III.17.Exchangeable Acidity and Aluminium

Start for Percolation, I Put 5gr of dried soil, ground to pass 2 mm on a funnel with a filter paper and put the funnel on a volumetric flask of 100ml, I added (on volume) 10 portions of 10 ml of k Cl 1N with a 15 minutes interval, I Carried to the mark with k Cl 1N and mix (solution of work: A), Made also a blank

III.17.1Determination of total exchangeable acidity

I Took 25 ml of the solution of work in an Erlenmeyer of 100 ml, I added 5 drops of phenolphthalein and titrate with NaOH 0.01 N until persistent pink color (wait 1minute)(solution A), noted the quantity in ml of NaOH used, titrated also the blank, calculation of Total Exchangeable Acidity (TAE), TAE (meq/100g of soil) = $\frac{(\mathrm{T}-\mathrm{bl})\times\mathbf{N}\times\mathbf{100}\times\mathbf{100}}{\mathbf{5}\times\mathbf{25}}$

III.17.2 Determination of exchangeable aluminium

Fade the solution A with HCl 0.01N (drop by drop), added 10 ml of Na F 4%(the solution becomes pink), titrated with HCl 0.01 N until total discoloration, noted the quantity in ml of HCl, titrated also the blank, calculation of Total Exchangeable Acidity (TAE), Al^{3+} (meq/100g of soil) = $\frac{(\mathrm{T}-\mathrm{bl})\times\mathbf{N}\times\mathbf{100}\times\mathbf{100}}{\mathbf{5}\times\mathbf{25}}$.

III.18. Method of determination of Bulk density (g /cm3)

The method used to measure is called core method (Black and Hartage, 1986). Briefly, the undisturbed soil samples in the core were used where the soil samples in the core were oven dried at 105°C and the way of calculating the bulk density uses the dry weight and core volume.

III.19. Electrical conductivity (EC)

EC was measured on 1:2.5 ratio extract with an electrical conductivity meter (Okalebo, 2002). Briefly, 25ml of distilled water were added to 10g of soil samples, shake for 30 minutes with a mechanical shaker, and stand for about 30 minutes to allow the soil sample to settle and measure the electrical conductivity using the conductivity meter.

III.20. Slope measurement

Measured slope position because it helped me to get the real value of land position**.**

Table 2: Laboratory methods for analysis of physical and chemical properties

Parameters	**Methods**	**References**
Physical properties		
Bulk density	Core method	Black and Hartge, (1986)
Soil texture	Hydrometer method	Bouyoucos, (1962)
Soilmoistureretention properties	Pressure plate and membrane apparatus	Klute, (1986)
Soil (pH) pH ($_{\text{Water}}$) pH ($_{\text{KCl}}$), pH (**$_{\text{NaF}}$)**	Potentiometrically using pH meter	Watson and Brown, (1990)National Soil Service, (1990)
Soil chemical properties		
Organic carbon	Wet oxidation	Nelson and Sommers, (1982).
Total Nitrogen	Micro- Kjedahl distillation	Bremmer (1996)
Available phosphorus	Bray and Kurtz1, determined by spectrophotometer at 884 nm wavelength	Bray and Kurtz, (1945).
Cation exchange capacity (CEC) and exchangeable bases	Saturation of soil with neutral 1M NH4OAc, adsorbed NH4^{+}displacedby 1MKClthen determination by Kjeldahl distillation for estimationof CEC, exchangeable bases measured by AAS.	Okaleboet al., (2002).
Exchangeable acidity	Titration	Okaleboet al, (2002).

III.21. Data collection

Soil samples were collected from the field using soil auger in depth of 0-30cm, 30- 60cm. After packaging and labeling them, samples were taken to the laboratory. Before laboratory analysis, some soil samples were dried in a free air crush at ambient temperature (about 25^{0}C) for several days and other soil samples were used as fresh soil according to laboratory methods and protocols.

III.22. Data analysis

Data collected were analyzed in University laboratory, Microsoft excel were used for data entry, management and used for graphical representation of the summarized data. Data record were analysed by using Genstat software version 4th edition for statistical analysis performance.Analysis of variance (ANOVA) performed after testing the variances of all data for normal distribution. Mean comparison were based on least significance differences (LSD) at 5 % probability level.

CHAP.IV. RESULTS PRESENTATION

VI.1. Bulk density

Bulk density of the studied soil were1.38g/cm3 for lowland, 1.44 g/cm3 middle and 1.66 g/cm3for up land. Bulk density of the studied soil were1.38g/cm3 for lowland, 1.44 g/cm3 middle and 1.66 g/cm3for up land.

Table 3: bulk density

Parameter	**Topographic feature**		
	Lowland	Middle land	Upland
Bulk density	1.38 g/cm^3	1.44 g/cm^3	1.66 g/ cm^3

VI.2. Soil moisture content

The results of laboratory analysis for soil moisture content are displayed in table 2.The soil moisture content measurements have been done in the laboratory by the use of oven drying method. The table 2 shows the average means value of soil moisture content. The low land has the mean of 51.1 % of S. Moist., the middle land has the mean of 27.2% of S. Moist., and the upper land has the mean of 21.7% of S. Moist.

Table 4: Moisture content

Parameter		**Topographic feature**	
	Lowland	Middle land	Upper land
Moisture content	21.92 g	11.64 g	9.32 g

VI.3. Soil depth

The different topographical features such as low land, middle land and upper land the value of soil depth are different for lower land is above 200 cm, for middle land is 50 cm and for upper land is 40cm.

Table 5: Soil depth

Topographic feature	Parameter	
	Soil depth	
Lowland	> 200 cm	Very deeper
Middle land	50 cm	Shallow
Upper land	40 cm	Very shallow

VI.4. Soil pH

The soil pH of the studied soil varies slightly between and among the soil depth (Table 4). The different depth soil are (0-30 cm) and (30-60 cm) was rated acidic to strongly acidic pH, was rated as powerfully acidic to medium acidic travel between 4.80 to 5.04 for pH of water and 3.95-4.48of KCl.

Table 6: Soil pH for different depth 0-30 cm and 30-60 cm

		Mean values pH water			**Mean pH KCl**	
	Low	Middle	Upper	low	Middle	Upper
0-30 cm	**5.13**	**4.98**	**4.80**	**4.48**	**3.97**	**3.95**
30-60 cm	**5.04**	**4.99**	**4.81**	**4.27**	**3.96**	**3.94**

VI.5.Organic carbon

The results of organic carbon are presented in (table5).The first part is lowland has the mean of 2.4% of O.C on depth of 0-30 cm and 2.4% of O.C on 30-60 cm depth, the second middle land has the mean of 1.5 % of O.C on depth of 0-30 cm and 1.505% of O.C on 30-60 cm depth, the third one is upper land has the mean of 1.4% of O.C on depth of 0-30 cm and 1.33 % of O.C on 30-60 cm depth.

Table 7: Mean values Soil organic matter

	Lowland (%)	Middle land (%)	Up land (%)
Depth(0-30)			
Mean	**2.449**	**1.528**	**1.415**
Standard Error	**0.378**	**0.215**	**0.0367**
Sum	**9.796**	**6.112**	**5.661**
ConfidenceLevel(95.0%)	**1.204**	**0.685**	**0.117**
30-60 cm			
Mean	**2.404**	**1.5055**	**1.3255**
Standard Error	**0.356**	**0.177**	**0.0225**
Sum	**9.615**	**6.022**	**5.302**
ConfidenceLevel(95.0%)	**1.134**	**0.564**	**0.0716**

VI.6. Electrical conductivity.

The soils of top soil on 0-30 cm EC ranges between 2.955- 3.843whereas the soil of 30-60 cm ranges between 2.087- 3.727 (table7).

Table 8: Mean Electrical conductivity

	EC(mS/cm or ds/m)		
	Low	Middle	upper
0-30 cm	**2.955**	**1.466**	**3.843**
30-60 cm	**3.727**	**2.087**	**2.657**

VI.7 Soil Texture.

In this site which has three different topographical feature like lowland, middle land and up land the silt fraction was very lowest respectively in lowland, the top soil (0-30 cm) is 9% and subsoil (30-60 cm) is 11%, for clay also is low on topsoil is 16.4% and for subsoil 18% but for sand fraction is highest than other fraction because the percentage of sand is on topsoil is 74.6% and for subsoil 71.6%. More details on topographical features are included in the following table (table 8). The soil we have found here in this site is sandy loam and loam sandy.

Table 9: soil Texture different depth 0-30 cm and 30-60 cm

Topographic feature for different depth	**% clay**	**% silt**	**%sand**	**Soil type**
Lowland 0-30 cm	16.4	9	74.6	Sandy loam
Lowland 30-60 cm	17.4	11	71.6	Sandy loam
Middle land 0-30 cm	9.4	10	80.6	Loam sandy
Middle land 30-60	11.4	8	80.6	Sandy loam
Upper land 0-30 cm	8.4	8	83.6	Loam sand
Upper land 30-60 cm	12.4	8	79.6	Sandy loam

VI.8 Available Phosphorous.

Available phosphorus within the studied soils ranges from 12.13 mg P/kg and from 12.02 mg P/kg for topsoil soil of 0-30 cm as soil depth and soil on 30-60 cm this is often for Lowland, 11.42 to 10.09 mg P/kg for topsoil of 0-30 cm as soil depth and soil on 30-60 cm this is often for middle land, 9.49 mg P/kg and 8.81 mg P/kg for topsoil of 0-30 cm as soil depth and soil on 30-60 cm this is often for up land severally. ILACO 1991; Landon1991; Baize 1993; Msanya et al., 2001), these values are often rated as moderate in each topsoil and subsoil also (Table 9).

Table 10: available phosphorous on different soil depth and different topographical feature.

	Lowland (meq/kg)	Middle (meq/kg)	Upper land (meq/kg)
0-30 cm			
Mean	**12.132**	**11.42**	**9.495**
Standard Error	**0.843**	**0.926**	**0.493**
Sum	**48.53**	**45.68**	**37.98**
ConfidenceLevel(95.0%)	**2.684**	**2.946**	**1.568**
30-60 cm			
Mean	**12.025**	**10.0975**	**8.81**
Standard Error	**0.419**	**0.580**	**0.851**
Sum	**48.1**	**40.39**	**35.24**
ConfidenceLevel(95.0%)	**1.333**	**1.848**	**2.711**

VI.9. Total Nitrogen.

The total nitrogen ranged for topsoil is 0.21% (low) and for subsoil is 0.15% in the low land, for middle land is 0.17% (low) on topsoil and for subsoil is 0.12% and for upland is 0.14% (low) on topsoil and for subsoil is 0.08% (Table 10). (ILACO, 1993; Landon, 1991; Baize, 1993; Msanya et al., 2001) and usually decreases with soil depth. According to Landon (1991),

Table 11: Total nitrogen

	low land (%)	**Middle land (%)**	**up land (%)**
0-30 cm			
Mean	**0.21**	**0.17575**	**0.137**
Standard Error	**0.041**	**0.034**	**0.034**
ConfidenceLevel(95.0%)	**0.130**	**0.108**	**0.109**
	0.117	0.136	0.143

30-60 cm			
Mean	**0.1535**	**0.1195**	**0.088**
Standard Error	**0.023**	**0.028**	**0.042**
ConfidenceLevel(95.0%)	**0.073**	**0.092**	**0.136**

VI.10.Cation Exchange Capacity

CEC, as reported by nearly all soil testing laboratories, is a calculated value which represents an estimated value of the soils ability to attract, retain, and exchange cation elements.

The studied soil has the CEC values ranged from 0.1086 cmol (+)/kg in topsoil, and 0.0819 cmol (+)/kg in subsoil for low land, 0.0571 cmol (+)/kg in topsoil, and 0.0435 cmol (+)/kg in subsoil for middle land and 0.0327 cmol (+)/kg in topsoil, and 0.0241 cmol (+)/kg in subsoil for up land (Table 11). In observance with (Landon, 1991; ILACO, 1993; Msanya et al., 2001), all topographic features within the study areas have low CEC in topsoil and extremely low CEC in subsoil.

Table 12: Mean Cation Exchange Capacity

	Lowland (cmol (+)/kg)	Middle(cmol(+)/kg)	Up land(cmol (+)/kg)
0-30 cm			
Mean	**0.1086**	**0.0571**	**0.0327**
Standard Error	0.0318	0.0162	0.0104
Sum	0.4344	0.2285	0.1311
ConfidenceLevel(95.0%)	0.1011	0.0514	0.0331
30-60 cm			
Mean	**0.0819**	**0.0435**	**0.0241**
Standard Error	0.0023	0.0013	0.0006
Sum	0.3275	0.1741	0.0964
ConfidenceLevel(95.0%)	0.0073	0.0041	0.0021

VI.11. Exchangeable acidity

VI.11.1. Exchangeable hydrogen

The Total exchangeable acidity which focused on the value of hydrogen, the values of exchangeable hydrogen on this soil study was0.88 meq/100gon topsoil and for subsoil is 0.34 meq/100gin the low land, for middle land is 1.92 meq/100gon topsoil and for subsoil is 1.72meq/100gand for upland is 0.3 meq/100gon topsoil and for subsoil is 1.16 meq/100g.

Table 13: Exchangeable hydrogen

-	low	Middle	Upper
(0-30 cm) Mean	**0.88**	**1.92**	**0.3**
Standard Error	0.255082	0.655642	0.128062
Sum	3.52	7.68	1.2
ConfidenceLevel(95.0%)	0.811784	2.086546	2.086546
(30-60 cm)Mean	**0.34**	**1.72**	**1.16**
Standard Error	0.1	0.458984	0.40464
Sum	1.36	6.88	4.64
ConfidenceLevel(95.0%)	0.318245	1.460693	1.287744

VI.11.1 exchangeable Aluminium (Al3+)

The exchangeable aluminium values were 1.28 meq/100g on topsoil and for subsoil is 1.42 meq/100g in the low land, for middle land is 1.44 meq/100g on topsoil and for subsoil is 2.36 meq/100gand for upland is 2.42 meq/100gon topsoil and for subsoil is 2.96 meq/100g.

Table 14: exchangeable Aluminium (Al3+)

	Low land	middle land	Upland
(0-30 cm)Mean	**1.28**	**1.32**	**2.42**
Standard Error	0.565685	0.147874	0.2579406
Sum	5.12	5.28	9.68
ConfidenceLevel(95.0%)	1.800263	0.4706	0.820882
(30-60 cm)Mean	**1.42**	**2.36**	**2.96**
Standard Error	0.249533	0.418887	0.5932959
Sum	5.68	9.44	11.84
ConfidenceLevel(95.0%)	0.794125	1.333087	1.8881323

VI.12 Exchangeable bases

In soil the main exchangeable cations are magnesium, potassium, calcium and the less extent nutrients addittion are sodium sodium, aluminium and hydrogen.

Table 2 : Exchangeable bases (cmol (+)/kg

	Na	**Ca**	**Mg**	**K**	
Depth(0-30cm)					
Lowland	0.004602	0.008399	0.005682		0.000756
Middle land	0.004507	0.0027	0.003873	0.000664	
Upper land	0.004127	0.011161	0.005243	0.000385	
depth (30-60cm)					
Low land	0.004338	0.004681	0.0052	0.00061	
Middle land	0.004641	0.005546	0.003866	0.0005	
Upper land	0.005184	0.008325	0.005098	0.00071	

Table 16: Mainecologicalrequirements for maizecrop in the studiedareascompared to the actualconditions in the field

Land use requirements) (Land quality)	Land characteristics (Diagnostic factor	Unit	Optimum Range (rate)	Actual field range			Rating		
				Lowland	Middle Land	Upper land	lowland	Middle land	Upper land
Moisture availability	Total rainfall in growing period	Mm	≥500mm in 3-4 months	1200-1281	1200-1281	1200-1281	S1	S1	S1
Temperature regime	Mean temperature in growing period	^{0}C	18 ^{O}C to 32^{O}C	18^{o}C	18^{o}C	18^{o}C	S1	S1	S1
Oxygen availability to roots	Soil drainage	Class	well drained	Well drained	Well drained	Well drained	S1	S1	S1
Rooting conditions	Effective soil depth	Cm	very deep	very deep	Shallow	shallow	S1	S2	S2
	Ground water level	Cm	>75cm	>30	>200	>200	S1	S3	S3
Nutrient availability	soil texture		Medium	fine textured	medium textured	medium textured	S1	S1	S1
	soil reaction (pH)		6.0 – 7.0	4.98	4.98	4.98	S3	S3	S3
	topsoil OC	%	High	Medium	Low	low	S2	S3	S3
	Topsoil TN	%	High	Medium	Low	low	S2	S3	S3
	Topsoil Avail P	Mg/kg	High	Low	Low	low	S3	S3	S3
Aluminium toxicity	Al. saturation	%	None	High	High	high	S3	S3	S3
Nutrient ret. Capacity	BS	%	High	Low	Very low	Very low	S3	S3	S3
	CEC	cmol(+)/kg	High	Medium	Low	low	S3	S3	S3
Salinity	Ece	(dS/m)	<5	<1.7	<1.7	<1.7	S1	S1	S1
Flooding hazard	Frequency of flooding		None	None	None	None	S1	S1	S1
Erosion hazard	Slope angle	%	**<4**	>16	>16	>16	S4	S4	S4

Table 17: Mainecologicalrequirements for bananascrop in the studiedareascompared to the actualconditions in the field

Land use requirements) (Land quality)	Land characteristics (Diagnostic factor	Unit	Optimum Range (rate)	Actual field range			Rating		
				Lowland	Middle Land	Upper land	lowland	Middle land	Upper Land
Moisture availability	Total rainfall in growing period	Mm	1250-2000	1200-1281	1200-1281	1200-1281	S1	S1	S1
Temperature regime	Mean temperature in growing period	^{0}C	16 ^{0}C to 30^{0}C	18^{o}C	18^{o}C	18^{o}C	S1	S1	S1
Oxygen availability to roots	Soil drainage	Class	Well drained	Well drained	Well drained	Well drained	S1	S1	S1
Rooting conditions	Effective soil depth	Cm	>80	very deep	shallow	shallow	S1	S3	S3
	Ground water level	Cm	>50cm	> 30	>200	>200	S1	S3	S3
Nutrient availability	soil texture		loamy sand	fine textured	medium textured	medium textured	S2	S3	S3
	soil reaction (pH)		6-7.5	4.98	4.98	4.98	S3	S3	S3
	topsoil OC	%	>1.5	Medium	Low	Low	S2	S3	S3
	Topsoil TN	%	>0.12	Medium	Low	Low	S2	S3	S3
	Topsoil Avail P	Mg/kg	>20	Low	Low	Low	S3	S3	S3
Aluminium toxicity	Al. saturation	%	None	High	high	High	S3	S3	S3
Nutrient ret. Capacity	BS	%	High	Low	Very low	Very low	S3	S4	S4
	CEC	cmol(+)/kg	High	Medium	Low	Low	S3	S2	S2
Salinity	Ece	(dS/m)	<5	<1.7	<1.7	<1.7	S1	S1	S1
Flooding hazard	Frequency of flooding		None	None	None	None	S1	S1	S1
Erosion hazard	Slope angle	%	0-1%	>16	>16	>16	S4	S4	S4

Table 18: Mainecologicalrequirements for cassava crop in the studiedareascompared to the actualconditions in the field

Land use requirements) (Land quality)	Land characteristics (Diagnostic factor	Unit	Optimum Range (rate)	Actual field range			Rating		
				Lowland	Middle land	Upper land	lowland	Middle land	Upper Land
Moisture availability	Total rainfall in growing period	Mm	400 -1 700	1200-1281	1200-1281	1200-1281	S1	S1	S1
Temperature regime	Mean temperature in growing period	^{0}C	16^{0}C - 29^{0}C	18^{o}C	18^{o}C	18^{o}C	S1	S1	S1
Oxygen availability to roots	Soil drainage	Class	Well drained	Well drained	Well drained	Well drained	S1	S1	S1
Rooting conditions	Effective soil depth	Cm	Very deep	very deep	shallow	shallow	S1	S3	S3
	Ground water level	Cm	>50cm	>30	>200	>200	S1	S3	S3
Nutrient availability	soil texture		loamy sand	fine textured	medium textured	medium textured	S1	S1	S1
	soil reaction (pH)		6.5	4.98	4.98	4.98	S3	S3	S3
	topsoil OC	%	High	Medium	Low	Low	S2	S3	S3
	Topsoil TN	%	High	Medium	Low	Low	S2	S3	S3
	Topsoil Avail P	Mg/kg	High	Medium	Low	Low	S2	S3	S3
Aluminium toxicity	Al. saturation	%	None	High	high	High	S3	S3	S3
Nutrient ret. Capacity	BS	%	High	Low	Very low	Very low	S3	S4	S4
	CEC	cmol(+)/kg	High	Medium	Low	Low	S2	S3	S3
Salinity	Ece	(dS/m)	<5	<1.7	<1.7	<1.7	S1	S1	S1
Flooding hazard	Frequency of flooding		None	None	None	None	S1	S1	S1
Erosion hazard	Slope angle	%	**<4**	>16	>16	>16	S4	S4	S3

Table39: Mainecologicalrequirements for sorghumcrop in the studiedareascompared to the actualconditions in the field

Land use requirements) (Land quality)	Land characteristics (Diagnostic factor	Unit	Optimum Range (rate)		Actual field range			Rating	
				Lowland	Middle land				Range (rate)
Moisture availability	Total rainfall in growing period	Mm	300 to 750mm	1200-1281	1200-1281	1200-1281	S1	S1	S1
Temperature regime	Mean temperature in growing period	^{0}C	18 ^{O}C to 30 ^{o}C	18^{o}C	18^{o}C	18^{o}C	S1	S1	S1
Oxygen availability to roots	Soil drainage	Class	Well drained	Well drained	Well drained	Well drained	S1	S1	S1
Rooting conditions	Effective soil depth	Cm	Very deep	very deep	shallow	Shallow	S1	S3	S3
	Ground water level	Cm	>50cm	>30	>200	>200	S1	S3	S3
Nutrient availability	soil texture		sandy soil	fine textured	medium textured	mediums textured	S1	S3	S3
	soil reaction (pH)		5.0 to 8.5	4.98	4.98	4.98	S3	S3	S3
	topsoil OC	%	High	Medium	Low	Low	S2	S3	S3
	Topsoil TN	%	High	Medium	Low	Low	S2	S3	S3
	Topsoil Avail P	Mg/kg	High	Low	Low	Low	S3	S3	S3
Aluminium toxicity	Al. saturation	%	None	High	High	High	S3	S3	S3
Nutrient ret. Capacity	BS	%	High	Low	Very low	Very low	S3	S4	S4
	CEC	cmol(+)/kg	High	Medium	Low	Low	S2	S3	S3
Salinity	Ece	(dS/m)	<5	<1.7	<1.7	<1.7	S1	S1	S1
Flooding hazard	Frequency of flooding		None	None	None	None	S1	S1	S1
Erosion hazard	Slope angle	%	Low altitude	>16	>16	>16	S4	S4	S4

Table 20: Mainecologicalrequirements for beanscrop in the studiedareascompared to the actualconditions in the field

Land use requirements) (Land quality)	Land characteristics (Diagnostic factor	Unit	Optimum Range (rate)	Actual field range			Rating		
				Lowland	Middle land				Range (rate)
Moisture availability	Total rainfall in growing period	Mm	≥300mm in 3 months	1200-1281	1200-1281	1200-1281	S1	S1	S1
Temperature regime	Mean temperature in growing period	^{0}C	15^{O}C to 27^{o}C	18^{o}C	18^{o}C	18^{o}C	S1	S1	S1
Oxygen availability to roots	Soil drainage	Class	well drained	Well drained	Well drained	Well drained	S1	S1	S1
Rooting conditions	Effective soil depth	Cm	very deep	very deep	shallow	Shallow	S1	S3	S3
	Ground water level	Cm	>50cm	>30	>200	>200	S1	S3	S3
Nutrient availability	soil texture		medium	fine textured	Medium textured	medium textured	S1	S3	S3
	soil reaction (pH)		5.5– 7.5	4.98	4.98	4.98	S3	S3	S3
	topsoil OC	%	High	Medium	Low	Low	S2	S3	S3
	Topsoil TN	%	High	Medium	Low	Low	S2	S3	S3
	Topsoil Avail P	Mg/kg	High	Low	Low	Low	S3	S3	S3
Aluminium toxicity	Al. saturation	%	None	High	High	High	S3	S3	S3
Nutrient ret. Capacity	BS	%	High	Low	Very low	Very low	S3	S3	S3
	CEC	cmol(+)/kg	High	Medium	Low	Low	S2	S3	S3
Salinity	Ece	(dS/m)	<5	<1.7	<1.7	<1.7	S1	S1	S1
Flooding hazard	Frequency of flooding		None	None	None	None	S1	S1	S1
Erosion hazard	Slope angle	%	Low altitude	>16	>16	>16	S4	S4	S3

Table 21: Mainecologicalrequirements for coffee crop in the studiedareascompared to the actualconditions in the field

Land use requirements) (Land quality)	Land characteristics (Diagnostic factor	Unit	Optimum Range (rate)	Actual field range			Rating		
				Lowland	Middle land				Range (rate)
Moisture availability	Total rainfall in growing period	Mm	1500	1200-1281	1200-1281	1200-1281	S1	S1	S1
Temperature regime	Mean temperature in growing period	^{0}C	12 ^{O}C -26^{o}C	18^{o}C	18^{o}C	18^{o}C	S1	S1	S1
Oxygen availability to roots	Soil drainage	Class	Well drained	Well drained	Well drained	Well drained	S1	S1	S1
Rooting conditions	Effective soil depth	Cm	Very deep	very deep	shallow	shallow	S1	S3	S3
	Ground water level	Cm	>50cm	>30	>200	>200	S1	S3	S3
Nutrient availability	soil texture		sandy-loam	fine textured	medium textured	medium textured	S1	S3	S3
	soil reaction (pH)		<5	4.98	4.98	4.98	S1	S1	S1
	topsoil OC	%	High	Medium	Low	low	S2	S3	S3
	Topsoil TN	%	< 0.16%	Medium	Low	low	S2	S3	S3
	Topsoil Avail P	Mg/kg	< 20ppm	Low	Low	low	S3	S3	S3
Aluminium toxicity	Al. saturation	%	>30%	High	High	high	S1	S1	S1
Nutrient ret. Capacity	BS	%	High	Low	very low	Very low	S3	S3	S3
	CEC	cmol(+)/kg	High	Medium	Low	low	S2	S3	S3
Salinity	Ece	(dS/m)	<5	<1.7	<1.7	<1.7	S1	S1	S1
Flooding hazard	Frequency of flooding		None	None	None	None	S1	S1	S1
Erosion hazard	Slope angle	%	**<4**	>16	>16	>16	S4	S4	S3

Table4:The suitability of landclassificationas the representativeareas of Mbazisector in Huyedistrict.

Landuse/ Studied area				**Rainfed Crops**		
	Coffee	**Maize**	**Banana**	**Sorghum**	**Beans**	**cassava**
Lowland	S3 na, nr	S3 na, x,nr	S3 na, x,nr	S3 na, x,nr	S3 na, x,nr	S3 na, x,nr
Middle land	S3 rc, na, nr,e,m	S3 rc, na, x,nr,e,m	S3 rc, na, x,nr,e	S3 rc, na, x,nr,e	S3 rc, na, x,nr,e	S3 rc, na, x,nr,e
Upperland	S3rc,na, ,nr,e,m	S3rc,na, x,nr,e,m	S3 rc, na, x,nr,m,e	S3 rc, na, x,nr,e,m	S3 rc, na, x,nr,e,m	S3 rc, na, x,nr,e,m

Limitations to suitability:

$S_{3:}$marginalsuitable, na:nutrientavailability,

x : toxicities, nr: nutrientretention,

e : erosionhazard,m: moisture available

CHAP. V. DISCUSSION

5.1. Bulk density

The bulk density is the indicator of soil compaction and affects infiltration, rooting depth, available water capacity, soil porosity and aeration, and availability of nutrients to plants as it affects soil organism. Soil bulk density has a major impact on the dynamics of water and air in the soil and crop root development which ultimately affects crop growth and yield (Uwingabire et al., 2016).For the various geographic feature lowland, middle land and upper land, we've got for this region. The majority bulk density of soil is influenced by organic matter content and tillage practices (Dilip Kumar Majumdar, 2004)). The values of bulk density are inside the common vary for tropical soils and these values recommend that studied soils weren't compact thus plant roots will penetrate simply and hence it cannot create any physical limitation for the agricultural purposes(Msanya et al., 2016). Low bulk density values in soil and their increase with depth are because of the rise in clay content and free oxides of iron, $Al^{3+}$and Mn^{3+} that are the cementing agents in soil and powerfully bind along individual soil particles(Mullins et al.,1992 and Karuma et al., 2015). The high bulk density in soils is as a result of more compacted and have less organic matter, less aggregation, and fewer root penetration compared to surface layers, thus contain less pore area (Dala and Mayer, 1986, Pikul et al., 2003).Soil bulk density features a major impact on the dynamics of water and air within the soil and crop root development that ultimately affects crop growth and yield. Therefore, deep soil is needed to enhance the majority density and so soil water uptake (Landon, 1991; Pikul et al., 2003). According toTenga et al., (2018), The soils with a bulk density less than 1.6 g/cm^3allow roots growth and these values suggest that studied soils were not compact hence plant roots can penetrate easily and it cannot pose any physical limitation for the tea purposes(Borah et al., 2009).Low bulk density values increase with depth due to the increase in clay content which is the cementing agent in soil and strongly bind together individual soil particles(Borah et al., 2009;Phogat et al., 2016). It also due to the surface layer which have high organic matter the majority density worth of higher land is high as a result of its soil texture (sand soil)and lower organic matter , except for low land its bulk density is lower because had higher organic matter than upland.

5.2. Soil moisture content

The results of laboratory analysis for soil moisture content are displayed in table 2.Highest values of wet were found in lowland occupied by high organic matter and sediment deposit, while lowest value of moisture content were found in middle land and upper land as a result of lower quantity of organic residue. The mean of moisture content for all topographical feature are show in(table 2).The results of this study is in line with Bandyopadhyay & Reza (2014), who asserted that the normal range of soil moisture content for crop plantation to be productive should be in 60-95% range. The studied soil result show that there is low amount water availability in upland compare to the lowland this is attributed to many factor as referencing to Mbaga, Msanya, & Mrema(2017),Tenga et al.(2018) and Uwingabire et al.(2016), who reported that the soil organic matter, particle size distribution, bulk density and structure of the soil influence the variation of available moisture content in the soil. the explanation of the structure of fine particles that doesn't contain pores or voids to carry water for these reason organic matter are able to increase soil organic matter which has the function of hold up in soil , increase pores in soil and has the perform of holding the little particle.

5.3. Soil depth

According to the soil depth there's a Penetration resistance that is employed to supply a relative measure of the resistance offered by soil to the penetration of roots, and is expressed because the magnitude relation between the forces needed pushing a metal cone into a soil versus the basal space of the cone (Lowery and Morrison, 2002). The depth of soil of the studied vary from 0-30 cm and sub soils range is from 30-60 cm , this depicts low penetration resistance within the higher soil that is attributed to low length of soil depth suggests that is shallow (Whaley, 2006). All different soil depth within the study areas has distinction increasing penetration resistance with soil depth (Table 3), Soil resistance will increase with increase in bulk density(Whaley,2006). The compactions within the soil of study space and which can cause Slow growth and development of crops (Kebeney et al., 2015).According to the different topographical features such as low land, middle land and upper land the value of soil depth are different for lower land is above 200 cm, for middle land is 50 cm and for upper land is 40cm. This implies that the penetration of roots aren't equivalent due to one aspect is shallow and alternative side is deeper.

5.4. Soil pH

Soil pH is the foundation of essential all soil chemistry and nutrient reaction, this parameter should be the first consideration when evaluating soil text. The pH range on scale is from 0 to 14 (Yadessa, 2010). Soil pH influences plant growth directly, via the effect of the hydrogen ions and via indirect to the effects of nutrient availability (Nyle B.et al,2002). The pH value in soil increases and aluminium (Al $^{3+)}$ exchangeable decreases by addition of Organic amendment and ash alkalinity. Basic cation content were the tests most closely correlated with increase in soil ph(Naramabuye et al.,2006). The acidity of the soils within the sites are largely contributed by high quantity of exchangeable Al, which might enter within the soil resolution and hydrolyzed to create group of Al compounds and free H+ that make the soil acidic(yahno and zouyah, 2008). This acidity of soil may be caused by higher rain, over cultivation and use of chemical fertilizers in the field. Since in higher rain areas, deep rooted perennial plants cut back the danger of action as they're able to grow quickly when the rains and capture soil water before leaching will occur(Mckenzie et al., 2004). Low hydrogen ion concentration within the study space is perhaps induced by acidifying chemical element fertilizer, nitrate action, removal of the bases through crop harvests and therefore the farming practices within the study space (McKenzie et al., 2004; Brady and Weil, 2008; and Landon, 1991). The strongly acid reaction values counsel attainable low handiness of each the macro and small plant nutrients for uptake by crops. Low soil hydrogen ion concentration values below pH < 5.5 have potential to cause toxicity issues and deficiency of some essential plants nutrients also as have an effect on soil microbe's activities (Adamchuk et al., 2005).It might conjointly cause dissolution of metal and iron minerals that precipitates with phosphorus effectively inflicting its fixation and more lowering the soil hydrogen ion concentration (Brady and Weil, 2008). The comparison of pH of KCl with pH of water provides associate assessment of the character of cyberspace charge on the mixture system. The distinction in hydrogen ion concentration results from displacement of OH– ions by Cl– ions. All soil within the study areas had positive delta hydrogen ion concentration (pH water - pH KCl) values, indicating that the exchange complexes of the mixture fractions of the soils are principally charged (Kebeney et al., 2015; Karuma et al., 2015). Most plants thrive well in soils of pH scale 6.5 to 7.5 (for non-calcareous soils) (Baize, 1993). The studied soils has the result of low pH values that can cause the limitations of crop growth, due to the absence of phosphorous and other nutrients

(Marschner, 1995), for Landon (1991) phosphate ions combines with iron and aluminium to make compounds that don't seem to be promptly accessible to plants in soils with pH scale of but 5.5.Application of liming materials could also be wanted to lift the pH scale to favorable levels of around pH 6.5 and 7.5. instead, crops that tolerate to acidity are suggested for as a result of plant species and varieties take issue within the degree to that they tolerate pH scale values outside the vary (EUROCONSULT, 1989). Under the different topographical feature the pH value was low because of use of over fertilizer, overcultivation without addition of amendment like organic matter, high level of slope which was caused the high speed of soil erosion.

5.5. Organic carbon

The results of organic carbon are presented in (table5).Low organic carbon in the study area may be due to overcultivation without another addition organic amendment. In general, the soil moisture contents that create conditions of poor aeration or slow oxidation, and differences in clay minerals, plant types might also contribute to the decomposition rate and the quantity of biomass to the observed differences (Nyle, C.B. and W.Ray, 2002). The low organic carbon maybe caused by lower value of pH because low pH inhibit the microbial activity, the removal of land cover and soil erosion may caused the organic carbon to be low. For lowland had medium organic carbon because of sediment deposit from top to bottom.

5.6. Electrical conductivity.

The electrical conductivity was a measure of relative salt concentration and the soil which contain too much amount of salt affect the growth of crop due to the root function and nutrient availability.The soils are non-saline as indicated by its low values of electrical conductivity. Soil has high EC than subsoil; this can be in all probability thanks to its high OM (Doerge et al., 2012). All soil on completely different geography feature (low land, middle land and up land) within the study space showed low values< 0.07 this show us that this soil is not fertile means that there is low CEC. The value of EC in the study soil analysis is<1.7ds/m. On the foundation of EC, it's been reportable that salinity effects are largely negligible if EC is below 2 dS/m at which yields of the many crops are restricted at EC of 4 through 8 dS/m whereas solely tolerant crops could yield satisfactorily at EC between 8 and 16 dS /m. Higher than 16 dS /m solely many terribly tolerant crops yield satisfactorily (US salinity Laboratory, 1954) cited by Hasinur 2008.

5.7 Soil Texture.

The soil particle size distribution results are presented in the following table with mean in the two sampling depth (0-30 cm) and (30-60 cm).More details on other topographical features are included in the table (table 8). The soil we have found here in this site is sandy loam and loam sandy.In three topographical feature lowland, middle land and upland the sand fraction was the highest compared to silt and clay respectively. The analysis of soil revealed that the soil of the three different topographical feature are sandy loam and loam sandy (table 8). The soil that is having this texture consists of big size materials whose behaviour is dominated by sandy. It most nearly resembles the sandy loam in that it has considerable amounts of sandy, which can be most easily detected by moistening the soil and smoothing it out between the fingers. However, as the loam sandy has more clay and silt than sandy loam means that it possesses greater cohesive properties like stickiness and the capacity of water holding and so on. For here the moisture content is low because of the deficient of organic matter and low essential nutrient in this soil.

5.8 Available Phosphorous.

The values of Available phosphorus are often rated as moderate in each top soil and subsoil also (Table 9). According to ILACO 1991; Landon1991; Baize 1993; Msanya et al., 2001), the medium values of P topsoil and subsoil of all topographical features (lowland, middle land) and low values for up land. This may probably be due to continuous cultivation with replacement of P from different P fertilizers in lowland and middle land but for upland the value of P is because there is no replacement of P fertilizer. The relatively low values of P in the soil of all topographical feature may be caused by the absent of anthropogenic effects including that no addition of manure, crop residue and inorganic P fertilizers and low potential for phosphorus fixation. Low offered phosphorus within the soil layers could also be attributed to low soil pH value (<5.5) that could react with iron (Fe) and aluminium (Al) to produce insoluble Fe and Al phosphates that are not readily available for plant uptake (Hodges, 2007). An available P level of 7-15 mg/kg is generally considered as the critical level below which P deficiency symptoms are likely to occur in many crops (Landon, 1991; Hodges, 2007; ILACO (1991). Addition of OM levels can help reduce any P ‘fixation’ reactions that may be present, by binding

Al, Fe and Ca, and forming soluble complexes with P which may be available to plants (Hodges, 2007). Obtained results confirm the study conducted by malirie et al.,(2007) starting that land use had an influence on phosphorous. Furthermore Organic matter and soil pH which depend on land use seem to have the impact on P availability. Recorded by Burt et al.,(2002,) there is a relationship between soil P and soil pH, organic carbon and the plot or place we have high value of coefficient determination indicate the relationship between available phosphorous in soil, soil pH and organic carbon. In brief, the areas which have high available P they must have high amount of organic carbon and high value of pH.

5.9. Total Nitrogen.

The low of TN discovered could also be attributed to low pH value that restricts microorganism activities. For PH values regarding 5.5 and below, microorganism activity is reduced and nitrification process on organic matter is considebly backward. Additionally the low chemical element levels discovered could also be attributed to erosion and continuing nutrient eliminating by plants. The comparatively lowest levels of N determined in soils of this totally different topographic feature for area could also be attributed to the absence of plant litter which might create the decomposition also as crop residues and application of each organic manure and inorganic chemical (Msanya et al., 2016). And also, the low value of TN in soils could also be caused by the continual cultivation while not replacement of organic residues (Kebeney et al., 2015). Nitrogen as gas could be a dynamic plant nutrient, which regularly desires replacement, as associate organic manure or as a mineral chemical as a result of its high risks of been lost from the soil either by leaching, intensities of soil erosion, soil texture types of crops grown and volatilization and brought up by plants (Kebeney et al., 2015). The C/N ratio values were 11.66% on depth of 0-30 cm and 16.025% on 30-60 cm depth, the second middle land has the mean of 8.988 % on depth of 0-30 cm and 10.036% on 30-60 cm depth, the third one is upper land has the mean of 10.107% on depth of 0-30 cm and 16.568% on 30-60 cm depth. If the soil has a C/N ratio which is greater than 25%, the decomposition of organic material is low. This cause the immobilization of nitrogen, means that the nitrogen production is very few and will not be available to any crops and the organic matter is low and is unlikely to break down quickly(Ping et al., 2014; Nuwategeka et al., 2016). Nutrient requirements for commercial tea production are high as the harvestable portions of tea contain the largest percentage of nutrients in the plant. N is the most important nutrient element for plant cultivation because it is required in large quantities. When the C/N ratio is below 25, application of nitrogen fertilizers tends to accelerate mineralization. The C/N ratio is important for the survival of microbial life which in turn perform virtually all the mineral transformation in soil(Mbaga et al., 2017).

5.10. Cation Exchange Capacity

The study areas have low CEC in topsoil and extremely low CEC in subsoil. The low values are contributed by the mineral known as kaolinite and sesquioxide or oxidic clays that are dominant clay minerals in extremely weather-beaten soils, lacking negative charges. Consequently, they don't retain adsorbate cations and find the low CEC because of the low nutrient retention capability (Landon, 1991). The CEC values within the topsoil are more than those in under soil (subsoil) for this different topographic feature like lowland, middle land and up land and this may be attributed to higher soil organic matter content (Tomašić et al., 2013). The CEC value typically increasing with increases of organic carbon; this might need been contributed by movement into and accumulation of clay within the sub-surface horizons (Pam and Brian, 2007).Landon (1991) and Pam and Brian (2007), reported CEC vary between fifteen (15) cmol (+)/kg to twenty five (25) cmol (+)/kg to be satisfactory for growth of most plants. The low CEC levels determined might even be attributed to low leaching as natural action instead strong runoff due to high erosion rate as these sites are steeply sloping space (30 - 60%). Erosion causes sediment loss from the upland part and deposition of new material within the lower part, this resulted in loss of nutrients within the upland part of the mountains.

The CEC of soils is determined by their SOM content and the type of minerals you have like type of clay minerals present, the role of SOM for exceeding the role of clay. Means that the CEC is crucial in soil fertility for two fundamental reasons such as the total quantity of nutrients available to plants or crops as exchangeable cations depends on it, and also it influences the degree to which hydrogen and aluminium ions occupy the exchange complex, and thus affects the pH of soils (Olaitan et al.,1986). According to Whitson and Chapman 1996), this CEC is an indication of this soil is not fertile because has lower value of CEC and SOM.

VI.11. Exchangeable acidity

The Total exchangeable acidity which focused on the value of hydrogen, the values of exchangeable hydrogen on this soil study was0.88meq/100gon topsoil and for subsoil is 0.34meq/100gin the low land, for middle land is 1.92meq/100gon topsoil and for subsoil is 1.72meq/100gand for upland is 0.3meq/100gon topsoil and for subsoil is 1.16meq/100g. The exchangeable aluminium values were 1.28 meq/100gon topsoil and for subsoil is 1.42 meq/100gin the low land, for middle land is 1.44meq/100gon topsoil and for subsoil is 2.36meq/100gand for upland is 2.42meq/100gon topsoil and for subsoil is 2.96meq/100g. Due to the variation of soil acidity and aluminium is based to the different topographical feature and different soil depth. According to Amberger (2006) the values of exchangeable aluminium is determined in the range**.** The increases of aluminium are based on the high leaching of cations and the high weathering of rocks.

VI.12 Exchangeable bases

The soils which can be roughly called silts and loams tend to have higher levels of calcium and magnesium but for the sand soil the exchangeable bases are very low and also for There Is High levels of soil acidity and aluminium. Means the soils which are generally more acidic tend to have more hydrogen and maybe aluminium and less calcium and magnesium**.**This study area the exchangeable base is very low because the soil has lower value of pH, means that there is acidity. Other problem cause the low value of exchangeable base is high leaching bases due to high of amount rainfall. These findings on the exchangeable bases content of the soils under the different land use types agree with those of saikh et al.,(1998), who reported a significant decrease in Ca2+ and Mg 2+, but insignificant changes in K+ and Na+ levels after conversion of forest to farmland.

V. CONCLUSION AND RECOMMENDATIONS

V.1. Conclusion

According to the results of our study, the conclusions are mentioned in the following sentences,

The climate, relief and parent material are participating in the influence on soil characteristics. Over cultivation, fertilizer application, deforestation, urbanization and other infrastructure as human activities without good management, they create many influences on soil as well as, through soil erosion in the way of removing top soil means fertile soil are removed directly. The soil of this study area are having low pH value, low organic carbon and organic matter, low nitrogen value, low value of phosphorus available, low level of CEC and low exchangeable bases. The value of pH is low, this may increase Phosphorus to be unavailability, reason why pH values below 5.5, P must associated with the aluminium and iron which cause the P to unavailable. The plants here suffer for lack of phosphorus availability. The presence sesquioxide show that the soils of Mbazi sector are dominated by kaolinite 1:1 silicate clay mineral and sesquioxides. For here these soils have high weathering stage means the soil nutrient removed quickly. The land of study area are marginally suitable for the beans , cassava, coffee, bananas, sorghum and maize with some limitations soil depth, moisture availability, nutrient availability, nutrient toxicity and erosion hazard.

V.2. Recommendation

According to the results of the study area the recommendation are given, as good strategies for this land the farmer plant the permanent crops coffee and macadamia with mulching strategies or mix crops with Agroforestry trees in the way of soil protection. This helps us in stabilizing the soil for soil erosion, roots fixation and reduce the leaching of cations. Try to create trench and terraces in the way of water conservation and infiltration of water is kept on mountainous areas. For here the cropping sustainability is achieved with the use of technological technics, in the way of increases the soil fertility we must use large amount of organic manure in the two ways mulching or incorporation method. And also farmers must mixed chemical fertility and organic manure in field application, the way of increases soil stability and soil fertility. In the way of solving the soil acidity problem, the farmers can made either liming, which is important in the raising the value of pH in the way of increasing pH levels around 6.5 to 7.5, other strategies is to plant tolerant crop to acidity are recommended as the best option. In the way of fighting the Al toxicity can be corrected by using the method of liming to the low pH ($pH>5.5$) in the way of precipitate the aluminium hydroxide. Second alternative is the method of using the organic matter in field, this also reduce Al toxicity by binding the Al ions in complex of organic matter.

For the research should be carried out in the way of assessing the soil suitability for given crop, this help to the available limitation in the field , amount available nutrient for crop, the level soil toxicity in the soil and also the degree of our land degradation.

CHAP.VI. REFERENCES

Akpoti, K., Kabo-bah, A. T., Zwart, S. J., Rice, A., & Ivoire, C. (2019). Agricultural land suitability analysis : State-of-the-art and outlooks for integration of climate change analysis. Agricultural Systems, 173(January 2018), 172–208. https://doi.org/10.1016/j.agsy.2019.02.013

Amiri, F., Ahmad, N., Space, N., & Balasundram, S. K. (2013). Agriculture Land Suitability Evaluator (ALSE): A decision and planning support tool for tropical and subtropical crops. (March). https://doi.org/10.1016/j.compag.2013.02.003

Background, C., Culture, T., Guide, B. C., Us, C., Guide, B. C., Us, S., & Enquiry, A. (2013). Banana Cultivation Guide « Banana Planters Banana Cultivation Guide « Banana Planters. 1

Caricasole, P., Hatcher, P. G., & Ohno, T. (2018). Biodegradation of crop residue-derived organic matter is influenced by its heteroatomic stoichiometry and molecular composition. Applied Soil Ecology, (May), 0–1. https://doi.org/10.1016/j.apsoil.2018.05.021

Chen, F., Ai, H., Wei, M., Qin, C., Feng, Y., & Ran, S. (2018). Ecotoxicology and Environmental Safety Distribution and phytotoxicity of soil labile aluminum fractions and aluminum species in soil water extracts and their effects on tall fescue. Ecotoxicology and Environmental Safety, 163(May), 180–187. https://doi.org/10.1016/j.ecoenv.2018.07.075

Cheng, Y., Li, P., Xu, G., Li, Z., Gao, H., Zhao, B., … Cheng, S. (2018). Soil & Tillage Research Effects of soil erosion and land use on spatial distribution of soil total phosphorus in a small watershed on the Loess Plateau , China. Soil & Tillage Research, 184(January), 142–152. https://doi.org/10.1016/j.still.2018.07.011

Dalanda, M., Wood, S. A., Diallo, A., Mahatma-saleh, M., Ndiaye, O., Kouly, A., … Guisse, A. (2016). Soil & Tillage Research Soil suitability for the production of rice , groundnut , and cassava in the peri-urban Niayes zone , Senegal. Soil & Tillage Research, 155, 412–420. https://doi.org/10.1016/j.still.2015.09.009

Department of Agriculture, F. and F. (2010). C assava production guideline.

District, R. (2013). Republic of Rwanda Rusizi District District Potentialities Assessment for the Integrated and Self-Centered Local.

Ebabu, K., Tsunekawa, A., Haregeweyn, N., Adgo, E., & Tsegaye, D. (2019). Science of the Total Environment Effects of land use and sustainable land management practices on runoff and soil loss in the Upper Blue Nile basin , Ethiopia. Science of the Total Environment, 648(August 2018), 1462–1475. https://doi.org/10.1016/j.scitotenv.2018.08.273

Elhakim, A. F. (2016). Estimation of soil permeability. Alexandria Engineering Journal, 55(3), 2631–2638. https://doi.org/10.1016/j.aej.2016.07.034

Fornasier, E., Fornasier, F., & Di, V. (2018). Spectrochimica Acta Part A : Molecular and Biomolecular Spectroscopy Spectrophotometric methods for the measurement of soil pH : A reappraisal. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 204, 113–118. https://doi.org/10.1016/j.saa.2018.06.029

Gu, W., Driscoll, C. T., Shao, S., Johnson, C. E., & Al, Þ. (2017). Forest Ecology and Management Aluminum is more tightly bound in soil after wollastonite treatment to a forest watershed. Forest Ecology and Management, 397, 57–66. https://doi.org/10.1016/j.foreco.2017.04.035

Guideline, P. (2012). spp. agriculture, forestry & fisheries.

Hillel, D. (n.d.). Soil Physics. 77–97.

Howeler, R. (2014). SUSTAINABLE SOIL AND CROP MANAGEMENT OF CASSAVA IN ASIA.

Keesstra, S. D., Rodrigo-comino, J., Novara, A., Pereira, P., Brevik, E., Pulido, M., … Gim, A. (2017). Runoff initiation , soil detachment and connectivity are enhanced as a consequence of vineyards plantations. 202, 268–275. https://doi.org/10.1016/j.jenvman.2017.07.036

Keesstra, S., Pereira, P., Novara, A., Brevik, E. C., Azorin-molina, C., Parras-alcántara, L., … Cerdà, A. (2016). Science of the Total Environment Effects of soil management techniques on soil water erosion in apricot orchards. Science of the Total Environment, 551–552, 357–366. https://doi.org/10.1016/j.scitotenv.2016.01.182

Kome, G. K., Enang, R. K., Palmer, B., Yerima, K., Gilles, M., & Lontsi, R. (2018). Geoderma Regional Models relating soil pH measurements in H 2 O , KCl and CaCl 2 for volcanic ash soils of Cameroon. Geoderma Regional, e00185. https://doi.org/10.1016/j.geodrs.2018.e00185

Lal, R. (2018). Soil & Tillage Research Accelerated Soil erosion as a source of atmospheric CO 2. Soil & Tillage Research, (July 2017), 0–1. https://doi.org/10.1016/j.still.2018.02.001

Liddicoat, C., Bi, P., Waycott, M., Glover, J., Breed, M., & Weinstein, P. (2018). Science of the Total Environment Ambient soil cation exchange capacity inversely associates with infectious and parasitic disease risk in regional Australia. Science of the Total Environment, 626, 117–125. https://doi.org/10.1016/j.scitotenv.2018.01.077

Liu, D., Huang, Y., An, S., Sun, H., Bhople, P., & Chen, Z. (2017). Catena Soil physicochemical and microbial characteristics of contrasting land-use types along soil depth gradients. Catena, (September), 0–1. https://doi.org/10.1016/j.catena.2017.10.028

Mcdowell, R. W., Snelder, T., Harris, S., Lilburne, L., Larned, S. T., Scarsbrook, M., … Taylor, K. (2018). The land use suitability concept : Introduction and an application of the concept to inform sustainable productivity within environmental constraints. Ecological Indicators, 91(March), 212–219. https://doi.org/10.1016/j.ecolind.2018.03.067

Mishra, A. (2016). Land Suitability Classification for Different Crops. (February).

Mustafa, A. A., Singh, M., Sahoo, R. N., Ahmed, N., Khanna, M., & Sarangi, A. (2011). Land Suitability Analysis for Different Crops : A Multi Criteria Decision Making Approach using Remote Sensing and GIS. 3(12), 61–84.

Nakao, A., Sugihara, S., Maejima, Y., Tsukada, H., & Funakawa, S. (2017). Geoderma Ferralsols in the Cameroon plateaus , with a focus on the mineralogical control on their cation exchange capacities. Geoderma, 285, 206–216. https://doi.org/10.1016/j.geoderma.2016.10.003

Nutrinet, H. (1996). Nutritional recommendations for banana.

Nzeyimana, I., Hartemink, A. E., & Graaff, J. De. (2013). Coffee farming and soil management in Rwanda. 42(1), 47–52. https://doi.org/10.5367/oa.2013.0118

Pohlan, H. A. J. (n.d.). M SC PL O E – C EO PL O E –.

Prakash, T. N. (2003). Land Suitability Analysis for Agricultural Crops : A Fuzzy Multicriteria Decision Making Approach.

Prażak, R. (2016). Prospects for Sorghum cultivation in Poland. 1–8. https://doi.org/10.5586/aa.1661

Production, D. P., Centre, R., Agricultural, D., & Services, I. (2008). Musa acuminata) 2008.

Qiao, J., Zhu, Y., Jia, X., & Huang, L. (2018). Catena Vertical distribution of soil total nitrogen and soil total phosphorus in the critical zone on the Loess Plateau , China. Catena, 166(December 2017), 310–316. https://doi.org/10.1016/j.catena.2018.04.019

REPUBLIC OF RWANDA SOUTHERN PROVINCE HUYE DISTRICT P . O . BOX 35 HUYE DISTRICT DEVELOPMENT PLAN. (2007). (June).

Rutebuka, J., Mbarushimana, D., & Verdoodt, A. (2019). Agriculture , Ecosystems and

Environment Farmers ' diagnosis of current soil erosion status and control within two contrasting agro-ecological zones of Rwanda. Agriculture, Ecosystems and Environment, 278(March), 81–95. https://doi.org/10.1016/j.agee.2019.03.016

Sainju, U. M., Allen, B. L., Lenssen, A. W., & Mikha, M. (2017). Biomass and Bioenergy Root and soil total carbon and nitrogen under bioenergy perennial grasses with various nitrogen rates. Biomass and Bioenergy, 107(March), 326–334. https://doi.org/10.1016/j.biombioe.2017.10.021

Shiri, J., Keshavarzi, A., Kisi, O., Iturraran-viveros, U., Bagherzadeh, A., Mousavi, R., & Karimi, S. (2017). Modeling soil cation exchange capacity using soil parameters : Assessing the heuristic models. Computers and Electronics in Agriculture, 135, 242–251. https://doi.org/10.1016/j.compag.2017.02.016

Sorghum, I., Africa, S., Africa, S., State, T. F., Sorghum, G., Hybrid, S., & Production, S. (1994). Sorghum production. 1–14.

To, A. G., & Production, S. (2013). SAVE AND GROW.

Vale, F., Jong, Q. De, Lier, V., Camargo, L. De, Pires, R. C. M., Ruiz-corrêa, S. T., … Dias, C. T. S. (2019). Soil & Tillage Research Tillage e ff ects on soil physical condition and root growth associated with sugarcane water availability. Soil & Tillage Research, 187(December 2018), 110–118. https://doi.org/10.1016/j.still.2018.12.005

Vasava, H. B., Gupta, A., Arora, R., & Das, B. S. (2019). Geoderma Assessment of soil texture from spectral re fl ectance data of bulk soil samples and their dry-sieved aggregate size fractions. Geoderma, 337(November 2018), 914–926. https://doi.org/10.1016/j.geoderma.2018.11.004

Vasu, D., Srivastava, R., Patil, N. G., Tiwary, P., Chandran, P., & Singh, S. K. (2018). Land Use Policy A comparative assessment of land suitability evaluation methods for agricultural land use planning at village level. Land Use Policy, 79(August 2017), 146–163. https://doi.org/10.1016/j.landusepol.2018.08.007

Verdoodt, A., & Ranst, E. Van. (n.d.). Land Evaluation for Agricultural Production in the Tropics A Two-Level Crop Growth Model for Annual Crops.

Vladimír, Š., Juriga, M., Jonczak, J., Uzarowicz, Ł., & St, W. (2019). Geoderma How relationships between soil organic matter parameters and soil structure characteristics are a ff ected by the long-term fertilization of a sandy soil. 342(February), 75–84.

https://doi.org/10.1016/j.geoderma.2019.02.020

Wairegi, L., Asten, P. Van, Giller, K., & Fairhurst, T. (2015). Banana-coffee system cropping guide.

Wei, S., Zhang, X., Mclaughlin, N. B., Chen, X., Jia, S., & Liang, A. (2017). Geoderma Impact of soil water erosion processes on catchment export of soil aggregates and associated SOC. Geoderma, 294, 63–69. https://doi.org/10.1016/j.geoderma.2017.01.021

Wei, W., Chen, D., Wang, L., Daryanto, S., Chen, L., Yu, Y., & Lu, Y. (2016). Earth-Science Reviews Global synthesis of the classi fi cations , distributions , bene fi ts and issues of terracing. 159(18), 388–403. https://doi.org/10.1016/j.earscirev.2016.06.010

West, N. (n.d.). Agriculture forestry and fisheries.

Xiong, Z., Li, S., Yao, L., Liu, G., Zhang, Q., & Liu, W. (2015). Topography and land use effects on spatial variability of soil denitrification and related soil properties in riparian wetlands. Ecological Engineering, 83, 437–443. https://doi.org/10.1016/j.ecoleng.2015.04.094

Xu, G., Cheng, S., Li, P., Li, Z., Gao, H., Yu, K., … Zhao, B. (2017). Soil total nitrogen sources on dammed farmland under the condition of ecological construction in a small watershed on the Loess Plateau , China. Ecological Engineering, (September), 0–1. https://doi.org/10.1016/j.ecoleng.2017.09.005

Yu, H., Huang, X., Ning, J., Zhu, B., & Cheng, Y. (2015). Effect of cation exchange capacity of soil on stabilized soil strength. Soils and Foundations, 54(6), 1236–1240. https://doi.org/10.1016/j.sandf.2014.11.016

Yvanes-giuliani, Y. A. M., Waite, T. D., & Collins, R. N. (2014). Science of the Total Environment Exchangeable and secondary mineral reactive pools of aluminium in coastal lowland acid sulfate soils. Science of the Total Environment, The, 485–486, 232–240. https://doi.org/10.1016/j.scitotenv.2014.03.064

Zhao, F. Z., Bai, L., Wang, J. Y., Deng, J., Ren, C. J., Han, X. H., … Wang, J. (2019). Catena Change in soil bacterial community during secondary succession depend on plant and soil characteristics. Catena, 173(January 2018), 246–252. https://doi.org/10.1016/j.catena.2018.10.024

Abebe Yadessa, 2010. Effect of different indegenous trees on the quality of wild arabica coffee in the affromontane rainforest of Ethiopia

Du Plessis, J., De Bruwer Dirk, Justinus M., Apie, P. and Thinus, P. (2003). Maize production. Grain Crops Institute Journal 4: 1 - 38.

Olaintan,S.O., Lombin G. and Onazi O.C.,1986. Introduction to tropical soil science.Macmillan publichers Ltd., London, UK.

FAO (1988).FAO-UNESCO Soil Map of the World. Revised Legend. World Soil Resources Report 60. FAO. Rome, Italy. 138pp.

MalorieR.,Joseph D., Laurent B. and Gilles Co., 2007. Effects of parent material and land use on soil phosphorus forms in southern Belgium. Gembloux Agro-Bio Tech, University of Liege.

Nyle,C.B. and Ray W.,2002. The nature and properties of soils. Thirteen edition, New Jersey USA.

FAOSTAT (2007).Statistics by Food and Agriculture Organization of the United Nations. [URL: http://faostat.fao.org] site visited on 12/12/2015.

USEPA. (2008). Registering Pesticides. Washington, D.C., 11–26.

Raemaekers, R.H. (2001). Crop Production in Tropical Africa.Directorate general for international Co-operation (DGIC), Brussels, Belgium. 1540pp.

WhitsonA.R. and Chapman C.J.,1996. A drill type lime and fertilizer sower.Extension service of the college of Agriculture.The university of Wisconsin.Madison.

NaramabuyeF.X.and Hynes R.J.,2006. Short term effects of three animal manures on soil pH and Al solubility Australian Journal of soil research,vol44, no5.

Verdoodt, A. and Van Ranst, E. (2003a). Land Evaluation for Agricultural Production in the Tropics: A Large Scale Land Suitability Classification for Rwanda. Laboratory of Soil Science, Gent, Belgium. 175pp.

Huye District (2013). Huye District Capacity Building Plan 2013-2018.Government printer, Huye, Rwanda.125pp.

Young, A. (1976). Tropical Soils and Soil Survey. Cambridge University Press. Cambridge. 468pp.

APPENDIX

				Rating		
crop	Land characteristics	Unit	S1	S2	S3	S4
maize	Total rainfall in growing period	Mm	≥500mm	500-400	≤ 400	<400
maize	Mean temperature in growing period	^{0}C	18 ^{O}C to 32^{O}C	18-16	≤ 18^{o}C	>32
maize	Soil drainage	Class	well drained	drained	less drained	not drained
maize	Effective soil depth	Cm	> 200	200-80	≤80	< 80
maize	Ground water level	Cm	>75cm	75-50	≤50	< 50
maize	soil texture		Medium	less medium	lesscaorses	verycaorses
maize	soil reaction (pH)		6.0 – 7.0	5.5-6	≤ 5.5	< 5
maize	topsoil OC	%	High	medium	Low	very low
maize	Topsoil TN	%	High	medium	Low	very low
maize	Topsoil Avail P	Mg/kg	High	medium	Low	very low
maize	Al. saturation	%	None	medium	High	very High
maize	BS	%	High	medium	low	very low
maize	CEC	cmol(+)/kg	High	medium	Low	very low
maize	Ece	(dS/m)	<5	≥5	>5	>5
maize	Frequency of flooding		None	low	medium	high
maize	Slope angle	%	**< 4**	≥ 4	>4	>4

Bananas	Total rainfall in growing period	Mm	1250-2000	≤ 1250	<1250	>2000
Bananas	Mean temperature in growing period	^{0}C	16 ^{0}C to 30^{0}C	≤ 16^{o}C	< 16^{o}C	>30
Bananas	Soil drainage	Class	Well drained	drained	less drained	none drained
Bananas	Effective soil depth	Cm	>80	≤ 80	shallow	very shallow
Bananas	Ground water level	Cm	>50cm	<50	>200	S1
Bananas	soil texture		loamy sandy	sandy loamy	caorse	verycoarse
Bananas	soil reaction (pH)		6-7.5	≤ 6	5.5	< 5
Bananas	topsoil OC	%	>1.5	≤ 1.5	low	very low
Bananas	Topsoil TN	%	>0.12	≤ 1.2	< 1.2	very low
Bananas	Topsoil Avail P	Mg/kg	>20	≤ 20	< 20	very low
Bananas	Al. saturation	%	None	low	high	Veryhigh
Bananas	BS	%	High	medium	low	very low
Bananas	CEC	cmol(+)/kg	High	medium	low	very low
Bananas	Ece	(dS/m)	<5	≥5	>5	>5
Bananas	Frequency of flooding		None	low	medium	High
Bananas	Slope angle	%	< **4**	≥ 4	>4	>4

cassava	Total rainfall in growing period	Mm	400 -1 700	≥ 400	≥ 1700	>1700
cassava	Mean temperature in growing period	^0C	16^0C - 29^0C	$\leq 16^oC$	$<16^o$**C**	>29
cassava	Soil drainage	Class	Well drained	drained	less drained	none drained
cassava	Effective soil depth	Cm	Very deep	deep	shallow	very shallow
cassava	Ground water level	Cm	>50cm	≤ 50	< 50	very less than 50
cassava	soil texture		loamy sand	sandy loamy	caorse	verycoarse
cassava	soil reaction (pH)		6.5	≤ 6.5	< 5.5	< 5
cassava	topsoil OC	%	High	medium	low	very low
cassava	Topsoil TN	%	High	medium	low	very low
cassava	Topsoil Avail P	Mg/kg	High	medium	low	very low
cassava	Al. saturation	%	None	low	high	very high
cassava	BS	%	High	medium	low	very low
cassava	CEC	cmol(+)/kg	High	medium	low	very low
cassava	Ece	(dS/m)	<5	≥5	>5	>5
cassava	Frequency of flooding		None	low	medium	High
cassava	Slope angle	%	**< 4**	≥ 4	>4	>4

sorghum	Total rainfall in growing period	Mm	300 to 750mm	≤ 300	≥ 750	> 750
sorghum	Mean temperature in growing period	^{0}C	18 ^{O}C to 30 ºC	≤ 18ºC	≥ 30 ºC	>30 ºC
sorghum	Soil drainage	Class	Well drained	drained	less drained	none drained
sorghum	Effective soil depth	Cm	Very deep	deep	shallow	very shallow
sorghum	Ground water level	Cm	>50cm	≤ 50	**< 50**	very less than 50
sorghum	soil texture		sandy soil	medium textured	caorse textured	verycaorses
sorghum	soil reaction (pH)		5.0 to 8.5	≤ 5	5 to 4	> 5
sorghum	topsoil OC	%	High	medium	low	very low
sorghum	Topsoil TN	%	High	medium	low	very low
sorghum	Topsoil Avail P	Mg/kg	High	medium	low	very low
sorghum	Al. saturation	%	None	low	high	very high
sorghum	BS	%	High	medium	low	very low
sorghum	CEC	cmol(+)/kg	High	medium	low	very low
sorghum	Ece	(dS/m)	<5	≥5	>5	>5
sorghum	Frequency of flooding		None	low	medium	High
sorghum	Slope angle	%	**< 4**	≥ 4	>4	>4

beans	Total rainfall in growing period	Mm	≥300mm in 3 months	≤ 300 mm	< 300 mm	very less than300 mm
beans	Mean temperature in growing period	^{0}C	15^{O}C to 27^{o}C	≤ 15^{o}C	< 15^{o}C	≤ 27oC
beans	Soil drainage	Class	well drained	drained	less drained	none drained
beans	Effective soil depth	Cm	very deep	deep	shallow	very shallow
beans	Ground water level	Cm	>50cm	≤ 50	< 50	very less shallow
beans	soil texture		medium	fine	caorse	verycaorse
beans	soil reaction (pH)		5.5– 7.5	≤ 5.5	5.5 to 4	< 5.5
beans	topsoil OC	%	High	medium	low	very low
beans	Topsoil TN	%	High	medium	low	very low
beans	Topsoil Avail P	Mg/kg	High	medium	low	very low
beans	Al. saturation	%	None	low	high	very high
beans	BS	%	High	medium	low	very low
beans	CEC	cmol(+)/kg	High	medium	low	very low
beans	Ece	(dS/m)	<5	≥5	>5	>5
beans	Frequency of flooding		None	low	medium	High
beans	Slope angle	%	**< 4**	≥ 4	>4	>4

coffee	Total rainfall in growing period	Mm	1500	≤ 1500	> 1500	> 1500
coffee	Mean temperature in growing period	^{0}C	12 ^{O}C -26^{o}C	≤ 12^{o}C	≥ 26 ^{o}C	> 26 oC
coffee	Soil drainage	Class	Well drained	drained	less drained	none drained
coffee	Effective soil depth	Cm	Very deep	deep	shallow	very shallow
coffee	Ground water level	Cm	>50cm	≤ 50	> 50	very less 50
coffee	soil texture		sandy-loam	fine texture	caorse textured	verycaorses
coffee	soil reaction (pH)		<5	> 5	high than 5	very high than 5
coffee	topsoil OC	%	High	medium	low	very low
coffee	Topsoil TN	%	< 0.16%	medium	high	very high
coffee	Topsoil Avail P	Mg/kg	< 20ppm	≥ 20ppm	>20ppm	>20ppm
coffee	Al. saturation	%	>30%	very low		S1
coffee	BS	%	High	medium	low	very low
coffee	CEC	cmol(+)/kg	High	medium	low	very low
coffee	Ece	(dS/m)	<5	≥5	>5	>5
coffee	Frequency of flooding		None	low	medium	high
coffee	Slope angle	%	**< 4**	≥ 4	>4	>4

APPENDIX

Appendix 1: Standards of pH interpretations in soil analysis

pH	Strongly acid	Very acid	Fairly acid	Slightly acid	Neutral	Slightly basic
pHwater	3,5 - 4,2	4,2 - 5,2	5,2 - 6,2	6,2 - 6,9	6,9 - 7,6	7,6 - 8,5
pHKCl	3,0 - 4,0	4,0 - 5,0	5,0 - 6,0	6,0 - 6,8	6,8 - 7,2	7,2 - 8,0

Source : Mutwewingabo and Rutunga, 1987

Appendix 2: Standards of interpretation for organic matter, C/N ratio, available phosphorus and exchangeable aluminum.

Organic matter (%)	Appreciation
0,5	excessiveVerylow
0,5 – 1	verylow
1 – 2	Low
2 – 5	middle
5 – 8	high
8 – 14	veryhigh
>14	excessiveveryhigh

C /N ratio	Mineralization
≤ 9	Very quick
9 – 12	Quick
12 – 17	Normal
17 – 25	Low
≥ 25	Very low
(Al ×100) /CECE	Limitation
≥ 60	Strong
30 – 60	Weak
≤ 30	Null to weak

Source : Mutwewingabo and Rutunga, 1987.

Appendix 3:Significance of ratios betweenexchangeable bases

Ratio	Scale	Deficiency or appreciation
Ca / Mg	< 1	Deficiency in Ca
	1 – 10	Optimum
	> 10	Deficiency en Mg
Mg / K	< 2	Deficiency in Mg
	2 – 20	Optimum
	> 20	Deficiency en K
(Ca + Mg) / K	< 12	Insufficiency of Ca and Mg

	12 – 30 > 30	Optimum Too high

Standards of interprétation for exhangeable bases, TSB, CEC, CECE, N total

Appreciation	Excessively weak	Very weak	Weak	Middle	High	Very high
ExhangeableCa (cmol(+)/kg)	-	< 2	2 - 4	4 – 10	10 - 20	> 20
Exhangeable Mg (cmol(+)/kg)	< 0.2	0.2 - 0.5	0.5 - 1.5	1.5 - 3.0	3.0 – 8.0	> 8.0
Exhangeable K (cmol(+)/kg	-	< 0.1	0.1 - 0.2	0.2 - 0.6	0.6 – 1.2	> 1.2
SBE (cmol(+)/kg)	< 1	1 – 2	2 - 6	6 – 10	10 - 30	> 30
CEC (cmol(+)/kg)	< 2	2 – 5	5 - 10	10 – 25	25 - 40	-
CECE (cmol(+)/kg)	-	-	4	4 – 7	> 17	-
TSB (%)	-	20	20 - 40	40 – 60	60 - 80	80 – 100
N total (%)	-	-	0.08-0.13	>0.13	-	-

Source :Mutwewingabo and Rutunga, 1987

Appendix 4: Interpretation of soilchemical values (Landon ,1991)

Analyze & unity	Mean values	Classification or qualification
CEC (cmol$_{(+)}$/kg de soil)	>40	Very high
	25-40	High
	15-25	Middle
	5-15	Weak
	<5	Very weak
% of bases saturation (ration in % of exhangeable bases and CEC)	>60	High
	20-60	Middle
	<20	Weak
Exhangeable bases (cmol$_{(+)}$/kg de sol)		
Calcium	>10	High
	<4	Weak
Magnesium	>4	High
	<0,5	Weak
Potassium	>0,6	High
	<0,2	Weak
Sodium	>1	High
	<1	Weak
Organic carbon in %	>10	High

	4-10	Middle
	<4	Weak
Total nitrogen (Kjeldahl) in %	>0,5	High
	0,2-0,5	Middle
	<0,2	Weak
Available phosphorus in ppm (for Bray method recommended for acidic soils)	>50	High
	50-15	Middle
	<15	Weak

Source: Landon J-R (1991)

Appendix 5. Standards of interpretation for available phosphorus

AvailablePhosphorus (ppm)	Significance
≤3	Very weak
3-20	Weak
20-50	Moderate
50-80	High
>80	Very high

Source : MUTWEWINGABO and RUTUNGA, 1987

Appendix 6. Standards of interpretation for CEC and total nitrogen

Analyze	Excessivelyweak	Veryweak	Weak	Middle	High	Veryhigh
C.E.C	<2	2-5	5-10	10-25	25-40	>40
Nitrogen (%)	-	-	<0.075	0.075-0.2	0.2-0.5	>0.5

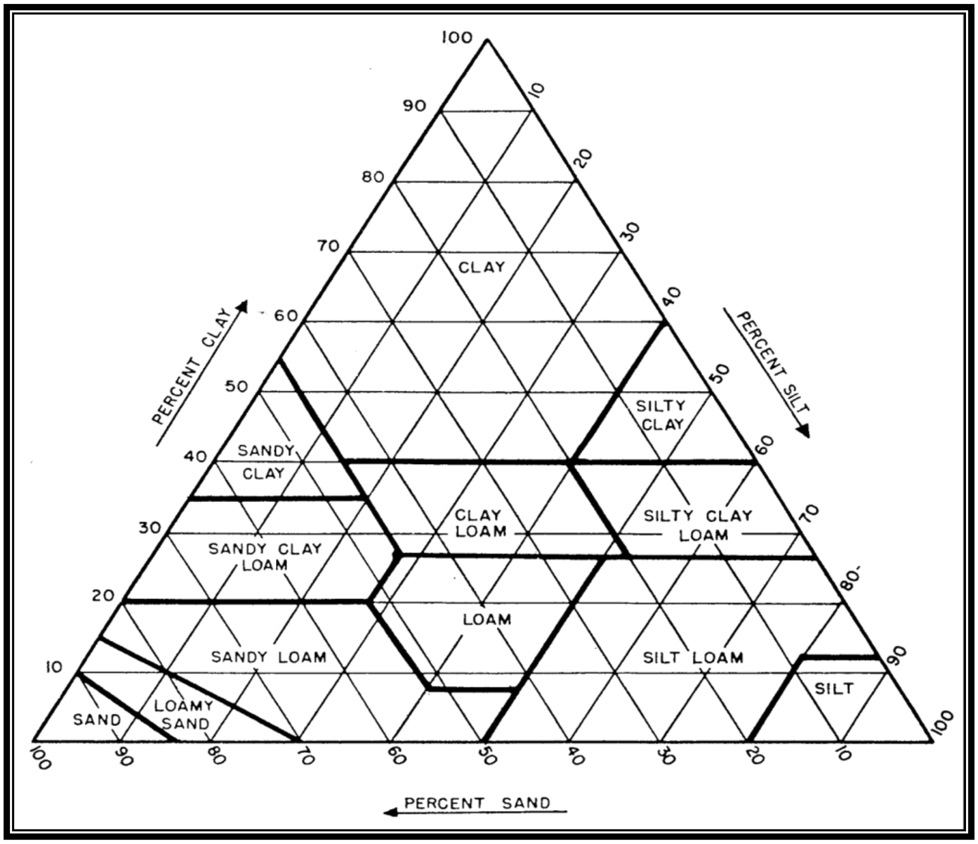
Source : MUTWEWINGABO and RUTUNGA, 1987.

Appendix 7: Standards of interpretation for field granulometry (International Society of soil sciences)

Clay	Slit	Sand		Stones
		Fine	gross	

0,002 0, 02 0,2 2,0mm Diam.

Appendix8: Texturaltriangle



Source : GUPTA, 2004

Appendix 9: Electricalconductivity

Soil type	EC range
Clay	10 – 1000mS/meter
Silt	5 – 50mS/meter
Sand	0.2 – 4mS/meter