LAND SUITABILITY ASSESSMENT FOR TEA PLANTATION IN RWANDA

CASE STUDY: GISAKURA TEA PLANTATION

By

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Declaration

I, INGABIRE Marie Ange, do hereby declare that though I have consulted other works during this dissertation preparation and use a series of sources cited in this work, this dissertation is the result of my own work and that has not submitted elsewhere for any other academic qualification at university of Rwanda or any other higher learning institution.

Signature Date

INGABIRE Marie Ange

(MSc Candidate)

The above declaration is confirmed

Signature Date

Prof. NARAMABUYE Francois Xavier

(Supervisor)

Signature Date

Dr Alain NDOLI

(Co-supervisor)

Dedication

This dissertation is dedicated to my family

Acknowledgements

My greatest thanks go to the almighty God for his abundant blessings and protection during my study and for guidance, wisdom and energy to carry out this work to completion.

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Abstract

Lack of information on land suitability for Tea plantation has induced yield variability and unproductive expansion in different agro ecological zones of Rwanda. This study was conducted in Gisakura tea plantation in Nyamasheke district in the Western Province of Rwanda. The objective was to assess soil chemical and physical suitability and site matching for tea plantation. The soil samples were taken at depths of topsoil (0-20 cm), middle soil (20-40cm) and subsoil (40-60cm) on both upland and lowland where new tea plantation would be established for extension of tea plantation. Soil chemical and physical properties were analyzed in laboratory using standard methods. Results showed that the soil was well drained with sandy loam and loamy sand texture. The analytical data show the high soil aggregate stability (0.64±0.051, 0.62±0.051 and 0.62±0.051 for the topsoil, middle soil and subsoil respectively), and low bulk density with maximum and minimum values of 0.2389±0.02005g/cm^3 and 0.2776±0.02005g/cm^3. The soil moisture retention characteristics have shown that soil water content decrease as the pressure increase and maximum water retention in upland and lowland was 72.6% and 66.9% while the minimum was 62.2% and 58.3% respectively. Chemically, the soil reaction was strongly acidic (pH values of 4.41±0.175, 4.065±0.175 and 3.954±0.175 units for the topsoil, middle soil and subsoil respectively) with medium to high exchangeable acidity. The soil was non saline with the electrical conductivity of 0.0518±0.00814dS/m, 0.0485±0.00814dS/m and 0.0416±0.00814dS/m for the topsoil, middle soil and subsoil respectively. The organic carbon was medium to high (518±0.721%, 0.0485±0.721% and 0.0416% for the topsoil, middle soil and subsoil respectively) and the organic matter content was high (10.79±1.244%, 9.91±1.244% and 6.08±1.244% for the topsoil, middle soil and subsoil respectively). The soil had very low total nitrogen (0.0709±0.00848%, 0.0661±0.00848% and 0.0362±0.00848% for the topsoil, middle soil and subsoil respectively), medium total phosphorous (0.02063±0.003385%, 0.02125±0.003385% and 0.02±0.003385% for the topsoil, middle soil and subsoil respectively) and deficient of available phosphorous (6.45±0.694ppm, 5.35±0.694ppm and 3.85±0.694ppm for the topsoil, middle soil and subsoil respectively). In order to improve the productive capacity of this soil to obtain high tea yield, remedial measures aiming at correcting the deficiencies should include liming to increase pH level to the level of availability of nutrients and utilization of organic manure with addition of inorganic fertilizers to provide the optimal level of nutrients.

Keywords: Tea plantation, land suitability, physical chemical suitability.

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Abbreviation and acronyms

Al	Aluminium
C/N	Carbon to Nitrogen ratio
pH	Hydrogen potential
EC	Electrical Conductivity
OC	Organic Carbon
OM	Organic Matter
TN	Total Nitrogen
P	Phosphorous
ºC	Degrees Celsius
%	Parcent
m	metre
cm	centimetre
mm	milemetre
m.a.s.l	metre above sea level
kg	kilogramme
g	gramme
cmol	centimols
dS	decisiemens
ppm	parts per million
ha	hectare
s.e	Standard Error
c.v	Coefficient of variation

FAO	Food and Agricultural Organization
NISR	National Institution of Statistics of Rwanda
GDP	Gross Domestic Product
NAEB	National Agriculture Export Board
GIS	Geographical Information System
CIAT	International Center for Tropical Agriculture
TRI	Tea Research Institution

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CHAPTER I: GENERAL INTRODUCTION

1.1 Background of study

Agriculture sector in Rwanda contributes to about 33% of the country gross domestic product (GDP) (Wold Bank, 2015). Tea and coffee are the major export commodities, contributing to more than 90% of export revenues (NISR, 2018; Bizoza, 2014). According to National Agriculture Export Board (NAEB, 2018) tea is cultivated on the total area of land of 34,262.8 hectares, giving the annual production volume of 25,000 metric tons of dry tea. Tea as main export crop play a important role in economic development of Rwanda where it has generated 55,408,500 US dollars from 16,818,324 kg of exported tea from July 2017 to February 2018 (NISR, 2018).

Tea was introduced in Rwanda in 1952 and mostly dominate tea are black, white, green, authentic and organic tea (NAEB, 2012). The physical relief of the main tea growing area is dominated by mountain range rising to about 2400 m a.s.l. These mountains consist mainly of steep slopes exceeding 25% (NAEB, 2012; T.R.I, 2002). Tea is planted on elevated land slopes at 1,900-2,500 m, in addition, it is adaptive in a well-drained marshland at 1550 and 1800 m (NAEB, 2012). The temperature for the tea production generally range between 21^oC to 29^oC where the minimum acceptable temperature is 16^oC (NAEB, 2012).

Land suitability is characterized as the fitness and ability of a given piece of land to well determined land use to give high production (Teka & Haftu, 2005; Verdoodt & Ranst, 2003). The land suitability is classified in suitable class and non-suitable class through the land suitability classification process which aims to define and evaluate a land use in relation to its appropriateness for a give function. Land suitability classification also referred to a current suitability because it clarifies the present status of the land with minor improved management practices (Sys & Debaveye, 1991; Mishra, 2016; Mohammad & Khan, 2014)

Land evaluation is expressed as valuation of land execution when utilized for defined purposes and it has principal objective of selecting the ideal land use for each characterized land unit (Darvishi-foshtomi et al., 2011). According to Gahlod et al. (2017), agro ecological land evaluation is used as a tool to foresee land behavior on every specific use, and soil quality assessment is used to anticipate the characteristic capacity of the soil to its role of providing a healthy condition for crops growth. Although, land assessment is not equivalent to soil quality appraisal, since during land assessment there is no measurement of biological factors of the soil.

Gahlod et al. (2017) reported that land suitability is defined as the measured land characteristics in their natural conditions in response to the crop requirements for growth and production up to the extent of the land unit quality which matches the necessity of a specific land use. Land appropriateness is the fundamental objective of all soil examination as it is a basic device for the land use characterization. Land suitability is also founded on the climatic condition such as the rainfall, temperature and altitude, and soil physical-chemical properties in terms of macronutrients and micronutrients, aggregate stability and percent sand, silt and clay (Khormali et al., 2007). Land suitability also helps to keep spatial soil data that are important for recommendation purpose.

The soil suitability study permits to identify the hindrance factor for crop production and helps to take decision for crop management system development to increase the profitability of land. Therefore, having more and sufficient information on land and soil characteristics is essential in formulating sustainable strategies for an ideal land development use plan (Gahlod et al., 2017). There is a large range of climatic, chemical and physical limiting factors that can restrict the suitability of different land use. Understanding those soil limiting factors for tea production would help in making policy on the sustainable planning and management of soils to increase the productivity (Khormali et al., 2007).

The selection of land according to its suitability has become increasingly important in making the best use of available land resource for tea production. Land can be classified according to its agricultural suitability (Verdoodt & Ranst, 2003; Teka & Haftu, 2005). The potential and limitations of land intended for tea-growing can be determined by its physical and chemical features. Land classification can simplify management and decision making on new planting, replanting, infilling, diversification and conservation of tea lands. It also helps to assess the long term production trends and investment needs for enhanced productivity (NAEB, 2012; T.R.I, 2002).Therefore this research aimed to characterize physical and chemical suitability for tea plantation in Gisakura in Nyamasheke district in the Western Province of Rwanda.

1.2 Problem statement

Low tea productivity in Rwanda is mainly due to mismanagement and unsuitable plantation in developing countries including Rwanda (Verdoodt & Ranst, 2003). The tea sector among export commodities increase the internal revenue and this led the government of Rwanda to expend the area of tea plantation by 20% through land consolidation and population expropriation (NAEB,2012). Despite the increasing of the new tea plantations, there is very little land suitability assessment undertaken on these new agriculture lands and the lack of this prior identification of suitable land, land is being replanted at high cost, but a good crop establishment is not achieved (Bandyopadhyay & Reza, 2014). Consequently, overexploitation, mismanagement and land degradation are linked to ignorance of basic soil quality factors governing productivity (Nuwategeka, Ayine, & Ofoyuru, 2016). Moreover, limited and lack of information on land suitability and crop requirement hinders farmer's decision on the best land use type. Several studies have suggested land suitability characterization for tea plantation before planting to achieve the target of producing high quantity with low cost of investment (Uwingabire et al., 2016).

In fact, there have been more research study which appraise the land ecological suitability for tea plantation and the focus was made on the geographical information system (GIS) by developing models for identification of suitable tea growing areas like the climate suitability for tea growth and climate suitability approaches for measuring the land use potential (Bo et al., 2012; Jayasinghe et al., 2019). However, there was few research on land suitability analysis for tea plantation focusing on the soil parameters as the soil have the major capacity to provide the required nutrients for tea. In order to obtain maximum returns from tea plantation, it is necessary to provide optimum conditions such as environmental and soil factors and could be used as a decisive tool in identifying suitable lands for tea cultivation and help to advice on improving unsuitable land in Rwanda.

1.3 Objectives of the Study

1.3.1 General objective

The main objective of this study was to characterize physical and chemical suitability for tea plantation in Gisakura.

1.3.2 Specific objectives

1. To evaluate soil pH, soil organic carbon, Total nitrogen, available and total phosphorus, electrical conductivity in new tea plantation area in Gisakura.
2. To assess soil texture, aggregate stability, bulk density, soil moisture content in new tea plantation in Gisakura

1.3.3 Research question

1. Are chemical and physical characteristics of the soil in Gisakura tea plantation suitable for tea growing?
2. What are the potentials and limitations of the soil for production of tea crops in Gisakura tea plantation?

CHAPTER II: LITERATURE REVIEW

2.1 Land Suitability

The term land includes many attributes such as climate, topography, soil and its genesis, vegetation, the presence of soil microorganisms and the effects of human activity (CIAT, 2017; Teka & Haftu, 2005). The land is said to be suitable when it is used for the specific purpose in the specific way to give an expected yield benefits that rationalize the proposed inputs without undesirable risk to land resources. While the unsuitable land has the features that prevent sustainable land use for production therefore it requires specific management and undesirable inputs at the time of used (Verdoodt & Ranst, 2003; T.R.I, 2002). The use of land according to its suitability class or mitigating the limiting factors is the key for increasing production (Hajiboland, 2017).

2.1.1 Land suitability classification

Every crop needs specific soil conditions and specific site conditions for its optimal growth as no all crops can't grow on the same condition either soil or climate condition (Mishra, 2016). During land suitability classification, Land are classified according to its fitness to a specific crop in association with the specific crop requirements and the actual potential of land characteristics (Verdoodt & Ranst, 2003). It also referred to a current suitability because it clarifies the present status of the land with minor improved management practices (Verdoodt & Ranst, 2003; Mishra, 2016; Mohammad & Khan, 2014).

There are limit on social, economic and physical factors that can be subject to obstructing the land fitness for different kinds of use (Bandyopadhyay et al., 2014). The comparison of plant necessities with its comparing qualitative land, climatic qualities and the most constraining attributes characterizes land suitability class through simple limitation technique (Darvishi-foshtomi et al., 2011). According to Mishra (2016) and Verdoodt & Ranst (2003), the FAO classify the land suitability in four suitability classes and those classes have subclass. The subclasses indicate the type of limitation and requirement measures for improvement within classes.

Land suitability classes

There are four suitability classes that are subjected to the fitness of land and are known as suitable classes (Highly suitable, moderately suitable and marginally suitable) and non-suitable class.

- **Class 1: Highly mostly Suitable land (S1)** is the land that does not have significant limitations on a given use in the sustainable way or just irrelevant restrictions that will not affect negatively the productivity or benefits and that will not require any additional contributions beyond the adequate level
- **Class 2: Moderately suitable land (S2)** is the land that have constraints on a given use and which are moderately serve for sustainable application.
- **Class 3: Marginally suitable land (S3)** is the land that have limitations on a given use and which in total are serve for supportable application and will affect negatively the productivity or benefits. This will require additional inputs on the expected ones and this extra spending will be just possibly defended.
- **Class N: Not suitable land (N)** is the land having limitation which show up as to disqualify any possibility of fruitful continued utilization of the land in the given way, or manageable limitations in function of time however, cannot be revised with existing knowledge at presently satisfactory cost. The areas under study does not have such kind of situation because even it temperature was noted as limitation but some crops can tolerate and once soil fertility improved, the production can be successful

Land suitability subclasses

Subclasses in land suitability show crop limitation and improvement measures required and are shown by the lower case letters as symbol.

- **C:** is the land showing the limitation of climatic conditions where the rainfall and temperature indicate the availability of moisture.
- **t:** is the land showing the topographic limitations where the topography and landscape indicate the resistance of land to erosion.
- **w:** is the land showing the wetness limitation where it indicates the available moisture, the soil drainage and flooding.
- **n:** is the land showing the limitation of salinity and/or alkalinity

- **f:** is the land showing the soil fertility constraints which is not willingly to be amended those are organic matter, cation exchange capacity (CEC), base saturation and nutrients availability.
- **s:** is the land showing the limitation of physical conditions such as soil texture, water availability, gravels and stoniness and availability of foot-hold for plant growth and soil depth which shows roots development. Physical conditions influence soil and water relationship and management.

2.1.2 Evaluation of land suitability

The evaluation of land suitability is an imperative component of the wider field for resource assessment (Mohammad & Khan, 2014). In agricultural context, the land evaluation comprises a comparison of physical requirements of crop growth with the characteristic or managed properties of land and gives a performance index, for example suitability index (Bandyopadhyay et al., 2014). According to Darvishi-foshtomi et al. (2011), The parametric land evaluation involves mathematical rating of a range of land limitation features depending on its range of minimum and maximum. Lastly, individual rating allows to estimate different indexes such as climatic and land.

Different methods such as parametric have been identified to assess land suitability for a given crop and was used to compute the Suitability index based on characteristics of environmental factors, drainage properties, soil physical and chemical properties (Sys & Debaveye, 1991). The following formula was elaborated:

$Ci = A*B/100*C/100*D/100*E/100*F/100$

Where:

- Ci is the suitability index
- A is the rating of prime factor
- B, C, D, etc. are remaining rating

The values of attribute are used to provide the suitability index for each land utilization type and the corresponding ratings of suitability and usually those values range from 0 to 100 this implies that a rating of 100 is assigned to the high suitable unit in any land evaluation. Therefore, computed values of suitability index are used to assess the relative suitability class for land.

The land suitability classes were defined referring to the suitability index:

- S1 (very suitable) class have indexes which are greater than 75
- S2 (moderately suitable) class have indexes which range in 50 to 75
- S3 (marginally suitable) class have indexes which range in 25 to 50
- N (not suitable) class have indexes which are less than 25

2.2 Suitable conditions for tea plantation

Tea is among the crops that demands specific requirements for growth to give the expected production (CIAT, 2017). There are many factors that determine land suitability for tea. The most important factors are climate, slope, soil depth, surface rockiness and gravel content (Bandyopadhyay et al., 2014) . Therefore, the importance in selecting a site for tea plant should be given on climatic and soil requirements before a decision is made on whether the area is suitable for tea due to the fact that certain of those factors could be limiting factors (Han, Li, & Ahammed, 2018). A simplified land suitability classification for tea can be based on limitation imposed by those factors and their interactions (T.R.I, 2002). Even though, tea was a dominant crop in humid tropics and subtropics regions, it shows a high adaptability capacity in a variable climate conditions (Khormali et al., 2007).

2.2.1 Climate

Tea plantation are mostly suitable in high rainfall area with monsoon lands. The ideal temperature for tea production ranging between 21^{o}C to 29^{o}C and the high temperature is required in summer while the lowest temperature for the growth of tea is 16^{o}C (Han et al., 2018; T.R.I, 2002; NAEB, 2012).

Table 1: Basic environmental requirements for tea growth and development (Bandyopadhyay et al., 2014)

Climate parameter	**Extreme lowest**	**Normal range**	**Optimum**
Temperature (^{o}C)	-20 to -8	13-26	18-23
Average rainfall (mm y^{-})	500	800-2500	1500-2000
Relative humidity per year (%)	60	70-90	80-85
Soil moisture (%)	50	60-95	70-90
Soil pH	3.0	3.5-6.5	4.5-5.5

2.2.1.1 Rainfall

The adequate lowest annual rainfall for the successful tea cultivation is 1,200 mm per year without irrigation but 2,500 mm to 3,000 mm per year is considered optimum (NAEB, 2012). It is impossible to judge whether rainfall is adequate on the annual total alone as distribution of the rainfall is of prime importance. Soil water is taken by roots systems and lost in the atmosphere by evapo-transpiration at a rate, which varies from 120 mm to 180 mm per month depending on the prevailing weather conditions. Ideally therefore water should be available to the roots in amounts which are of this order each month (CIAT, 2017). Where there are prolonged periods when rainfall is less than the water lost by evapotranspiration, the plants must rely on stored ground water (Han et al., 2018). When considering rainfall, it must be remembered that in the extremely dry years, the rainfall may be only two-thirds of the long-term average, and such dry years may occur once in every ten years. It is important to note that such a pattern may or may not occur.

2.2.1.2 Temperature

Tea like other has the optimum temperature in which it can grow, low temperature disturb tea growth whereas the optimum temperature should not be too low or too high. Although this tea survives the winter months (Han et al., 2018). However, the temperature which is under freezing is considered to be unfriendly to tea growth when it is followed with rapid increase of day time temperature and it lead to leaf scorch (T.R.I., 2009). It also assumed that, generally lowest air temperature lower than 13^{o}C are likely to bring damage to foliage. Research has shown that various tea clones exhibit different responses to air temperature in what is known as base temperature for shoot extension and development. Soil temperature has the effect on plant life compare with the air temperatures. In Kenya it has been shown that rate of tea growth is influenced by soil temperature and it hence yield. The optimal soil temperature within the feeder root depth of the soil is 20^{o}C to 25^{o}C (T.R.I, 2002).

2.2.2 Altitude

Temperature is inversely related to altitude, this means that the higher is the altitude, the lower the temperature is (Teka & Haftu, 2005) . It has been found in Kenya that, within certain limits, there is a negative linear relationship between yields of tea and altitude at which it is grown (T.R.I, 2002; T.R.I., 2009). Utilizing long term mean yield information of tea domains situated at different elevation from 1,500 m to 2,250 m and equation has been calculated which suggests that the average annual tea yield reduced by 200 kg made tea to every hectare for each 100 m rise in elevation (Khormali et al., 2007). The decrease in yield can be more when considering high yielding clones, which are sensitive to temperature changes (NAEB, 2012). This fall in tea production with rise in altitude is directly attributed to fall in temperature. It is therefore important to take note of this information when considering a site for tea planting (Khormali et al., 2007).

2.2.3 Water availability

The water availability is another key point, which control tea growth and productivity. In fact, drought is responsible for yield reduction between 14 to 20% and increase about 6% to 19% of tea plants mortality (NAEB, 2012; Hajiboland, 2017). In spite of the fact that the total annual precipitation in the majority of the rain-fed growing region is adequate for tea production (Hajiboland, 2017).

2.2.4 Soil

In general, tea is grown in the slightly acidic soil without calcium content (NAEB, 2012). Therefore, it is very important that the acidity of the soil have to be investigated and only those areas found to have suitable pH are planted without any pH correction treatment (Bandyopadhyay et al., 2014) . Generally, the soil with pH between 4.0 and 6.0 is, suitable for tea. The best soil for tea while other factors are not limiting; varies in the range of pH 5.0 to 5.6. The availability of the base nutrients such as potassium, magnesium, calcium, and phosphate are likely to become deficiency as the soil reaction goes below 5.0 (Hajiboland, 2017). In soils of pH above 5.8, there are often problems of establishing tea and it is recommended to treat soil pH at planting (Bandyopadhyay et al., 2014).

Tea is developed in assortment of soils; however, the best is alight friable topsoil with permeable subsoil which allows free percolation of water, tea is grown in a deep well drained soil with over 2% of organic matter. It is considered that for tea at least two meter (2 m) of soil depth should be considered to allow the free lines of tea roots, this is very important for a successful tea area. (NAEB, 2012; Hajiboland, 2017). According to Hajiboland (2017), There are other characteristics to be considered for economic tea production include the field slope, grayeliness and soil rockiness. The soil which has depth of under 50 cm, graveliness which is over half and rockiness of 20% influence the development of tea critically. Tea which develop in shallow and compacted soils are probably going to experience the stress of dry season and waterlogging during the rainy months.

2.2.5 Land

Tea cultivation needs well-drained land. Practically all the industrially tea plantation are situated in the highlands and on hill slopes where the natural drainage is good. Tea cannot endure standing water and waterlogged lowlands are in this way least fit to tea development. Mountain slopes have been adopted for tea regions of the rainy season lands (NAEB, 2012). Mostly, tea prefer the land which are steep sloping, even though there is severe soil loss by erosion which is regularly an issue, it can be addressed by planting tea along the contour lines (Teka & Haftu, 2005).

2.3 Evaluation of land suitability for tea

A number of studies related to diverse characteristics of land suitability evaluation for tea have been conducted based on FAO framework in different countries using the parametric evaluation method proposed by Sys & Debaveye (1991) and the soil and land characteristics was used to evaluate the fitness of tea. Those characteristics include environmental factors, drainage properties, soil physical and chemical properties.Gahlod et al. (2017) studied the land-site suitability evaluation for tea in Wayanad district, Kerala using the parameters namely organic carbon, soil depth, pH, texture, EC, Slope, and altitude. In that study soil-site suitability criteria table was developed referring to the Sys & Debaveye (1991) suitability class table from the suitability index for interim match for tea. Verdoodt & Ranst (2003) assessed and evaluated the land suitability classification for tea in Rwanda based to the climate (annual rainfall and dry season), Slope, flooding, drainage, clay content, soil depth, and base saturation. Based on the kind of production limitations, the suitability classes for tea were determined and are presented in the tables below for the two studies respectively.

Table 2: Soil requirements for tea by Gahlod et al. (2017)

Soil suitability class, degree of limitation and rating scale				
Suitability class	S1	S2	S3	N1
parametric Evaluation of restrictions crop	100-75	75-50	50-25	25-0
Soil-site characteristics				
Climatic and land quality				
Mean temperature (^{o}C)	18-25	26-28	29-30	>30
		15-17	13-14	<13
Mean RH (%)	>80	60-80	60-50	<50
Total rainfall (mm)	1800-2000	1600-1800	1000-1600	<1000
Length of growing season (days)	>240	240-180	180-150	<150
Texture (class)	scl, l, cl, sl	c, sicl, sic	c(ss), ls,s	
pH (1:2.5)	4.5-5.0	5.1-6.0	6.1-6.5	>6.5
		4.4-4.0	<4.0	
Soil depth (cm)	>150	100-150	50-100	<50
EC (dSm1)	Non saline	<1.0	1.0-2.0	-

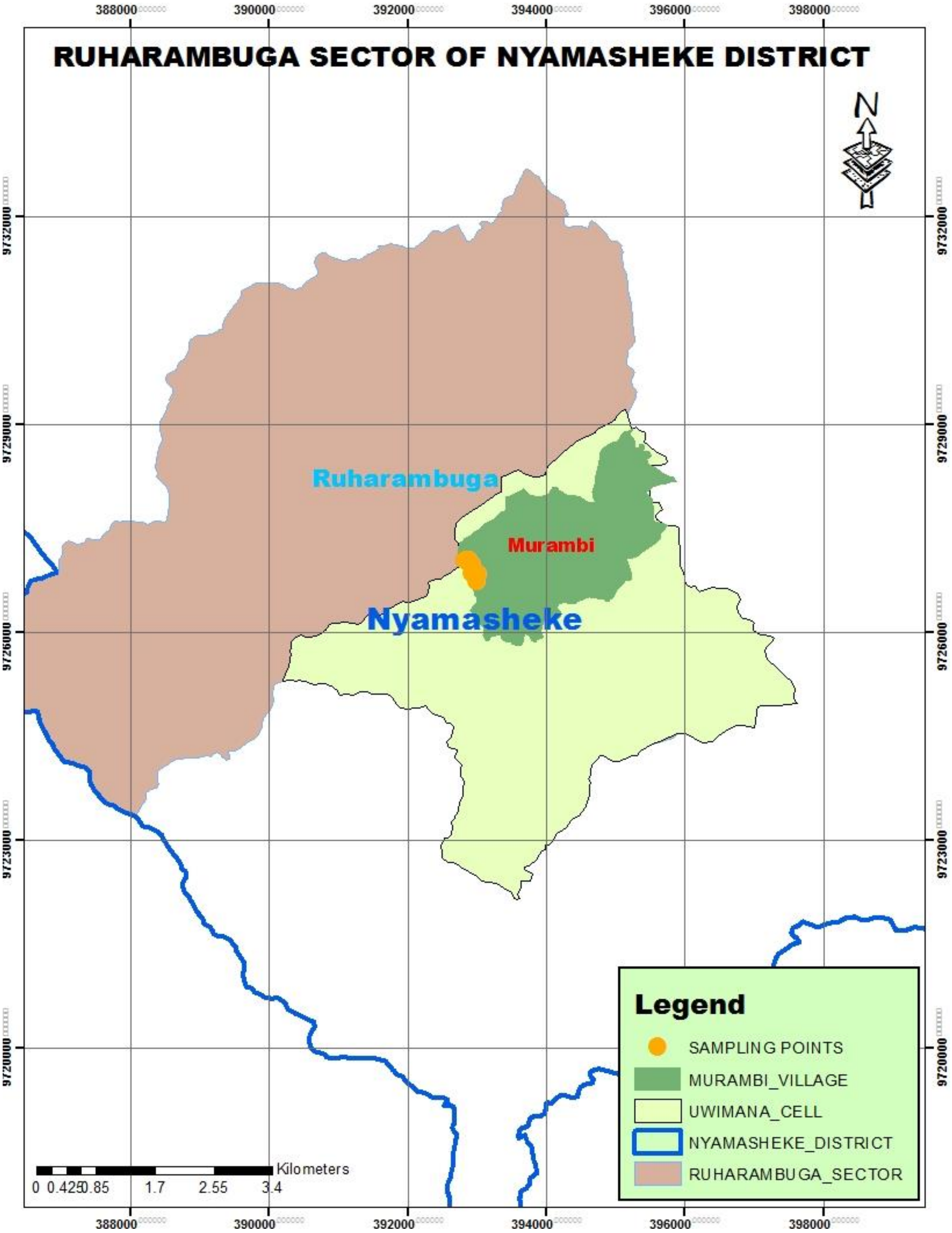
Table 3: Soil requirements for tea in Rwanda by Verdoodt & Ranst (2003)

Soil suitability class, degree of limitation and rating scale				
Suitability class	S1	S2	S3	N1
parametric Evaluation of restrictions crop	100-75	75-50	50-25	25-0
Soil-site characteristics **Climatic and land quality**				
Annual rainfall (mm)	>1300	1300-1200	1200-1100	<1100
Dry season (days)	<60	60-90	90-120	>120
Slope (%)	<13	13-25	25-55	>55
Flooding	no risk	-	-	any risk
Drainage	excessive to moderate	imperfect	poor	very poor
Clay % & structure	35-60 blocky 20-35	> 60 Blocky < 20	-	
Depth (m)	> 1.00	0.50-1.00	< 0.50	-
SBC (cmol/kg)	> 2.0	< 2.0	-	-
Base saturation (%)	< 20	20-35	35-50	>50

CHAPTER III: MATERIALS AND METHODOLOGY

3.1 Site Description

Gisakura tea plantation region under study is found in the Congo Nile Watershed divide in Rwanda. This agro ecological zone is characterized by tropical climatic conditions for the tea growth. The Gisakura tea plantation region under study is located in Murambi village, Wimana cell, Ruharambuga sector, Nyamasheke district in the western province of Rwanda. Topographically, the Nyamasheke district is characterized by hilly landscape with the altitude of 1555 m of altitude and its geographical position is at S 2^{o} 22' and E 29^{o} 09'. Nyamasheke District is caharacterized by tropical climate with an average annual temperature of 18.6 ^{o}C, where the temperatures are highest on average in September at around 19.1^{o}C, the lowest average temperature in the year occur in June when the it is around 18.2^{o}C. Its average annual rainfall is 1364mm where the summers are much rainier than the winters. it has surface area of 1,174 km^2 with overall density of 324.9/km^2. The main cash crops that have been planted in the district was coffee on 4,962 ha and tea on 3,547 ha in 2012 through the program of land consolidation and crop intensification (DDP, 2018; NISR, 2014).


RUHARAMBUGA SECTOR OF NYAMASHEKE DISTRICT
N
388000
390000
392000
394000
396000
398000
9732000
9729000
9726000
9723000
9720000
Ruharambuga
Murambi
Nyamasheke
Legend
SAMPLING POINTS
MURAMBI_VILLAGE
UWIMANA_CELL
NYAMASHEKE_DISTRICT
RUHARAMBUGA_SECTOR
Kilometers
0 0.425 0.85 1.7 2.55 3.4

3.2 Soil Sampling Method and Procedure

The soil samples were taken from the field under study, where undisturbed soil samples were taken and kept in core, and disturbed soil samples was taken using an auger and kept in polythene plastic bugs for laboratory analysis of chemical and physical parameters.

Using transect walks, auger observation and descriptions; the investigation of field survey for grouping the representative study point basing on the slope gradient, landforms, natural vegetation, vegetation index, soil colour, soil texture, and other physiographic attributes, the site was grouped in homogenous zones. The landscape was hilly and the soil samples were taken on two different slope gradients considered as upland and lowland. Conferring to the principle of random and equal multipoint mixing, the "Y" shape points was used to collect samples and divided the sampling depth into topsoil (0 to 20 cm), middle soil (20 to 40 cm) and bottom soil (40 to 60 cm). the sampling design was split plot design where those different soil depth was used as subplot. Each sample was gathered by mixing four pre-samples taken at each half hectare (0.5 ha) and by using the GPS, geographic position of each sampling point was recorded. The total of twenty-four composite samples were collected to present the area under study and prepared for analysis.

The topsoil sample could very easily be taken with one auger dip, and was uncontaminated provided that the tool was clean. The outer part of the soil in the twist bit was scrapped lightly with a knife to reduce contamination of sample. The middle soil sample was obtained by inserting the auger tool in the same hole, turning the handle until the 40 cm file mark was reached, and then pulling up and removing the sample in the convolutions of the twist bit as above. When pulling up the middle soil sample it was almost impossible to have some topsoil not dropping into the hole. In order to remove this, the auger was inserted and drilled about 5 cm, pulled up and the soil discarded. The bottom soil sample could be taken quite cleanly (T.R.I., 2009).

3.3 Laboratory analyses

Laboratory activities were conducted in Soil Science Laboratory of university of Rwanda. The collected disturbed soil samples were air-dried and crushed to pass through a 2 mm and 5 mm sieve for laboratory analyses. Undisturbed core samples were used for the determination of bulk density and soil moisture retention characteristics while the disturbed soil samples were used for determination of other physical and chemical properties of soils.

Soil moisture retention characteristics

Soil moisture retention characteristics was assessed using sand kaolin box for low suction values and pressure apparatus for higher suction values (NSS, 1990). Briefly, the undisturbed soil samples in the core were used. A piece nylon cloth was fixed to the bottom side of the core with an elastic band on all sample core. The soil samples were placed in the sand box with the bottom side down and wait for one hour to allow the samples to be covered with water through the percolation movement. Deferent pressure (pF=0, pF=0.4, pF=1, pF=1.5, pF=1.8, pF=2) was applied to the soil samples in sand box and weights of nylon, elastic band, core and soil were recorded at each pressure applied when there was no water from the sand box. After the soil samples and cores were oven dried at 105^{o}C 24 hours. Using the pressure apparatus for higher suction (3 bar, 5 bar, 10 bar and15 bar), the soil retaining rings with the filter paper of know weight were filled with saturated disturbed soil and put the plate with filled ring in the pressure membrane apparatus and the different pressure were applied and weight of rings, soil samples and filter paper were recorded and after the samples were oven dried at 105^{o}C for 24 hours finally the gravimetric soil moisture content was calculated.

Bulk density (BD)

BD was determined using 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^{o}C and the bulk density was calculated using dry weight and core volume.

Particle size

Hydrometer method was used to determine the particle size after scattering the soil with sodium hexametaphosphate concentrated on 5% (NSS, 1990). The textural classes were determined using the USDA textural class triangle (USDA,1975). Briefly, 50 gr of soil sample sieved in a 2 mm sieve were taken, added 125 ml of deionized water, added 5 ml of hydrogen peroxide and put in bain-marie at 90°C for 2 hours and allow to cool. 10 ml of Calgon were added and shake with the dispersing shaker machine and transferred in the 1 ml graduated cylinder and bring to the mark with deionized water. Then after the readings of hydro meter and thermometer was recorded.

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.

Soil pH

Soil pH was measured potentiometrically in water and in 1N KCl at a ratio of 1:2.5 soil: water and KCl (Okalebo, 2002). Briefly, 10g of soil were taken and put in 25ml of distilled water and KCl and shake for 30 minutes with a mechanical shaker and stand for about 30 minutes to allow the soil sample to settle and measure the pH for both water and KCl using the pH meter.

Total Exchangeable acidity

Total exchangeable acidity was determined using 1M KCl extraction solution and the soil extract titrated with sodium hydroxide. A second titration with 1M HCl after addition of sodium fluoride was done for obtaining the exchangeable aluminium (NSS, 1990).

Organic Carbon (OC)

OC was designed using Walkely and Black oxidation wet method (Nelson and Sommers, 1982). Organic matter was estimated from organic carbon using 1.724 as a conversion factor (Duursma and Dawson). Briefly, 0.3 gr of soil sample to pass in 0.5mm were taken and put in 500 ml Erlenmeyer flask added 10 ml of dichromate solution and 20 ml of surfiric acid, swirled and stand for 30 min and add 100 ml of distilled water and 10 ml phosphoric acid and 2 ml of indicator and ferrous sulphate was used for titration.

Total Nitrogen (TN)

TN was measure from digestion using an electrical hot plate in a fume hood and colorimetric determination (Okalebo, 2002). The hydrogen peroxide, sulphuric acid, selenium and salicylic acid was used in measurement of total nitrogen content from the digest obtained. Briefly, 0.5 gr of soil sample crushed 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, allow cooling and pull it in a volumetric flask of 100 ml and bring to the mark with distilled water. The entire digest was diluted to a ratio of 1:9 with distilled water and with the micropipette 0.2 ml of digest was taken and pulled 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.

Total Phosphorus (TP)

TP was determined by digestion using an electrical hot plate in a fume hood and colorimetric determination (Okalebo, 2002). The ascorbic acid was use for the measurement of total phosphorous content in a digest obtained. Briefly 0.5 gr of soil sample crushed to pass in 0.5 mm were taken and put in a mineralization tube and added 1.5 gr of catalyst and add 10 ml of H_2SO_4 concentrated, allow cooling and pull it in a volumetric flask of 100 ml and carried to the mark with distilled water. With the micropipette 5.0 ml of digest were put into a 50 ml volumetric flask and add about 20 ml of the distilled water and 10 ml of ascorbic acid reducing agent and brought to the mark with distilled water, shake well and allowed to stand for 1 hour to develop the full blue color. Finally, the absorbance was measured at 880 nm on UV spectrophotometer.

Available phosphorus

Bray no 2 method was used for the measurement of available phosphorus 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).

3.4 Data analysis

Microsoft Excel was used for data entry and producing tables and graphs. The data was organized and entered into Genistart software fifteenth edition for analysis of variance and for mean separation.

CHAPTER IV: RESULT AND DISCUSSION

4.1 Soils

Generally, the studied soil is classified as ferralsols referring to the FAO soil taxonomy, which are deep soil with red or yellow color resulted from the high contents of iron and aluminium oxides. Geologically, ferralsols are formed from high weathered parent materials and dominated with oxides and kaolinite clay minerals. Physically, ferralsols are soil have fine textured subsurface layer of low silt to clay ratio with a good aeration which allows the movement of air and water and allow roots to be well develop, and have high capacity of internal drainage. Chemically, they are acidic soil with low pH and have low fertility due to the leaching of bases and nutrients. They have low holding capacity and are generally low in organic contents which induce the nutrients availability to plants. They require addition of lime and fertilizer to increase fertility when they are to be use for agriculture (IUSS, 2014; Bockheim, et al., 2014; Amberger, 2006; Verdoodt & Ranst, 2003). Two soil properties were measured in the assessment of land suitability, namely, soil physical and chemical properties.

4.1.1 Soil physical properties

The soil particle size distribution and aggregate stability results are presented in this table with their coefficient variation (CV) of mean and standard error (SE) in the three sampling depth; topsoil (0-20 cm), middle soil (20-40 cm) and subsoil (40-60 cm).

Table 4: Ferralsol physical properties (proportions of sand, silt, and clay and aggregate stability) in Gisakura tea plantation in 2019

Soil depth	Sandy (%)	Clay (%)	Silt (%)	Aggregate stability
0-20	81	6.7	12.3	0.64
20-40	81.5	8.38	10.12	0.62
40-60	82	10.0	8	0.62
s.e (5% level)	2.582	1.459	1.981	0.051
l.s.d	3.088	1.714	4.571	0.05
CV (%)	3.2	17.5	19.5	8.1

Particle size distribution

The mean particle size distribution of studied soils are presented in the table 4. The results show that the texture class of studied soils was dominated by loamy sand and a little sandy loam. According to Hazelton & Murphy, (2007), the sand content is very high in the studied soil and varies with soil depth. The topsoil has 81% ±2.582, middle soil has 81.5% ±2.582, and subsoil has 82% ±2.582 with c.v of 3.2% these results indicate that the variation of mean of sand was uniform distribution in the field and increase with soil depth. This is most likely depend on the parent material and the current land use on the field. There is an increase in sand particle content with soil depth due to the low aggressiveness of erosive agents and the high organic matter content in top soil as the was not cultivated long ego and is covered by grasses the low aggressiveness of erosive agents. The coarse textured soils with more than 65% sand and less than 18% clay usually have low fertility status (Abam & Orji, 2019; Phogat et al., 2016).

The clay content of the studied soils was 6.7% ±1.459, 8.38% ±1.459 and 10.0% ±1.459 of topsoil, middle soil and subsoil respectively with c.v of 17.5%. The results indicate that the variation of mean of clay was uniform distribution in the field and increase with soil depth, this is due to the weathering of parent material, translocation of clays and the current activity on the field (Durak & Dogan, 2010; Phogat et al., 2016). According to (Hazelton & Murphy, 2007), the clay content in the studied area ranked as very low from topsoil to low in subsoil for the whole field soil. It has reported that clay interact with organic matter and increase water and nutrient holding capacity. The studied soil has low holding capacity of nutrients and water as we know that the soil which contain more than 20% clay has high capacity of holding water and nutrient knowing that clay increase aggregate stability by acting like cementing agent and protect the soil against raindrop. It also decrease surface sealing (Abam & Orji, 2019; Durak & Dogan, 2010), This will increase the internal drainage of soil.

Silt content of the studied soils was 12.3% ±1.981, 10.12% ±1.981 and 8% ±1.981 of topsoil, middle soil and subsoil respectively with c.v of 19.5%, these results indicate that the variation of mean of silt was uniform distribution in the field. There is a decrease of silt content with depth and the soil was rated as low silt content (Hazelton & Murphy, 2007). This low values indicates that the soil doesn't have enough capacity for retaining available water for plant growth (Abam & Orji, 2019; Durak & Dogan, 2010; Phogat et al., 2016). The studied soil has more macro pores due to the high sand particle content and very low silts which leads to low micropores. It known that macropores are quickly drained while micropores hold water which is used by crop. The soil texture results which is sand loamy and loamy sand is favorable on tea growth as supported by Nuwategeka et al., (2016) who said that a well drainage sand loamy soil is suitable for tea growth. The results revealed that the site under study meet the requirements in terms of textural condition for tea plantation.

Aggregate stability

Studied soil has the aggregate stability of 0.64±0.051, 0.62±0.051 and 0.62±0.051 of topsoil, middle soil and subsoil respectively with c.v of 8.1% (table 4). The results show variation of mean of aggregate stability was uniform distribution in the field and was ranked as high with referring to the work of Hazelton & Murphy (2007) and Phogat et al., (2016) who reported that the values of aggregate stability greater than 0.03 is high. This implies that the soil has resistance to the external complex agents that may destroy the soil. The findings are matched with standard requirement for tea plantation as aggregate stability enhance infiltration rate and proper roots distribution.

Bulk density

Studied soil have the bulk density which ranges between 0.2389±0.0200.5g/cm^3 and 0.2776±0.0200.5g/cm^3 with the c.v of 7.8% and in the table below. these result indicate the uniform distribution of bulk density in the field and was rated as very low when matched with the critical levels of bulk density (very low when is less than 1.0 g/cm^3, low when it is 1.0-1.3 g/cm^3, moderate when it is 1.3-1.6 g/cm^3, high when it is 1.6-1.9 g/cm^3 and very high when it is greater than 1.9 g/cm^3) (Hazelton & Murphy, 2007). Soil compaction is indicated by the bulk density and affects infiltration, rooting depth, available water capacity, soil porosity and aeration, and availability of nutrients to plants as it affects soil organism. The dynamics of air and water in the soil and crop roots development is affect by the bulk density, this finally affects crop growth and yield (Uwingabire et al., 2016). According to Tenga et al., (2018), The soils with a bulk density less than 1.6 g/cm^3 allow 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 bulk density is very low this implies the intensive soil disturbance may cause the land to slide; therefore, growing the perennial crops like tea is favorable to reduce intensive tillage and to increase the soil structure due to deeper roots of tea.

Table 5: Bulk density of soils in Gisakura tea plantation on ferralsols in 20l9

S/N	**Bulk density (g/cm^3)**
1	0.2776
2	0.2551
3	0.2389
4	0.2505
s.e (5% level)	0.02005
l.s.d	0.0638
CV (%)	7.8

Soil moisture characteristics curves of the soil under study

The Figure below presents result on soil moisture retention characteristics for the studied soil. Soil water content in the upland and lowland decrease as the pressure increase from the saturation point to the permanent wilting point. The findings indicate that the maximum water retention in upland and lowland was 72.6% and 66.9% while the minimum is 62.2% and 58.3% respectively. The results of this study is in line with Bandyopadhyay & Reza (2014), who asserted that the normal range of soil moisture content for tea plantation to be productive should be in 60-95% range. The studied soil result show that there is high water rotation capacity in upland compare to the lowland this is attributed to many factor as refereeing to Mbaga, Msanya, & Mrema (2017), Tenga et al. (2018) and Uwingabire et al. (2016), who stated that soil organic matter, particle size distribution, bulk density and structure of the soil influence variation of available moisture content in the soil. In fact, the result of soil particle size distribution show that the upland has much clay content compare to the lowland (appendix1) which implies the high holding capacity of water. The high organic matter content induces the water holding capacity due to its different functional group. The particle size distribution and bulk density determine distribution of macropores and micropores density, which influence soil water retentions.

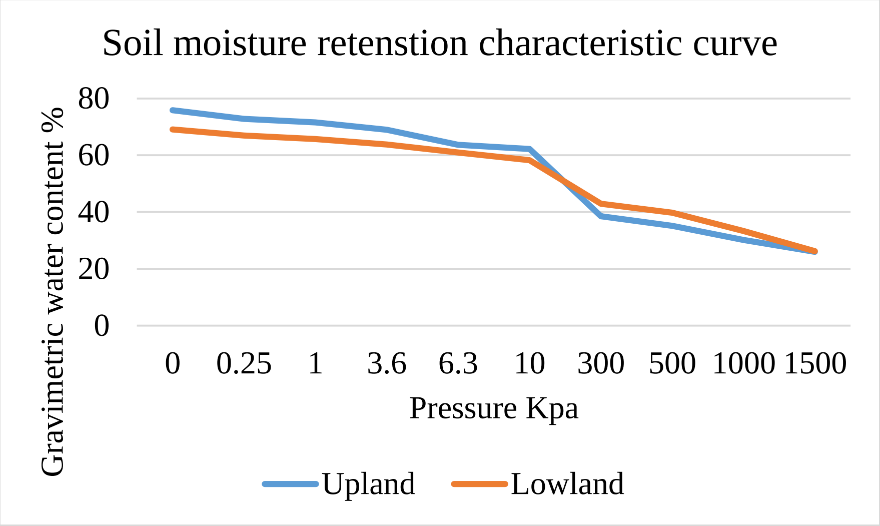


Figure 1: Soil moisture characteristics for the site of Gisakura tea plantation in 2019

4.1.2 Soil chemical properties

The soil chemical parameter results of studied soil are presented in the table below with their coefficient variation (CV) of mean and standard error (SE) in the three sampling depth; the topsoil (0-20 cm), middle soil (20-40 cm), and subsoil (40-60 cm).

Table 6: Ferralsol chemical properties (pH, EC and exchangeable acidity) in Gisakura tea plantation in 2019

Soil depth	pH water	pH KCl	Exch. Al^{3+} (cmol/kg)	Exch. H^+ (cmol/kg)	EC (dS/m)
0-20	4.41	4.099	6	1.17	0.0518
20-40	4.292	4.065	6.64	1.05	0.0485
40-60	4.291	3.954	7.35	0.87	0.0416
s.e (5% level)	0.175	0.0701	0.806	0.1054	0.00814
l.s.d	0.0638	0.2264	0.585	0.1405	0.00733
CV (%)	4	1.7	12.1	10.2	17.2

Soil pH

The soil reaction is a main factors determining crop yield through its effect on nutrients availability in soil solution. The soil pH values of the studied soils were 4.41±0.175, 4.292±0.175 and 4.291±0.175 of topsoil, middle soil and subsoil respectively with c.v of 4% (table 6). The results indicate that the variation of mean of pH was uniform distribution in the field and was ranked as strongly acidic with referring to the work of Hazelton & Murphy (2007) and Mbanga et al. (2017) who reported that the values of pH varies between 4 and 4.5 is moderately acidic. The pH values decrease with the soil depth and this implies that the soil acidity increase as you go down in depth this is due to the organic matter that are in the topsoil. The soil acidification was attributed to the excessive leaching of nitrate and exchangeable bases and their replacement with exchangeable acidity especially under the high rainfall conditions of the study area. and organic material decomposition (Abam & Orji, 2019; Chude at al., 2004). It is known that the soil macro and micro nutrients availability to plant depend on the soil reaction and the strong acidic reaction advocate low availability. Low soil pH values below pH<5.5 have potential to cause toxicity problems and deficiency of some essential plants nutrients as well as affect soil microbial activities.

The soil pH result of the studied area are in line with those of Ping et al., (2014) and Gahlod et al., (2017) saying that the soils in which tea is grown are usually acidic in nature and the maintenance of an optimal soil pH (5.0-5.6) while other factors are not limiting is important in tea cultivation as soil pH decreases below 5.0, there is lack of the basic cations. Therefore, soil amendments should be endeavored to improve soil for meeting the optimal pH range of tea growth as the pH is <5.0. Mostly, the amendments used for soil reaction when the pH is less than 4.5 are dolomite and lime. Furthermore, tea has capacity to absorb Al^{3+} and store it in old leaves, thus it requires an adequate supply of exchangeable Al and Fe. High aluminum induce crop stunting and mortality.

Exchangeable acidity

The exchangeable hydrogen values of the studied soils were 1.17±0.175cmol/kg, 1.05±0.175cmol/kg and 0.87±0.175cmol/kg of topsoil, middle soil and subsoil respectively with c.v of 10.2% (table 6). The exchangeable aluminium values were 6±0.806cmol/kg, 6.64±0.806cmol/kg and 7.35±0.806cmol/kg of topsoil, middle soil and subsoil respectively with c.v of 12.1% and it increase with soil depth. This is due to the increase of the acidity of soil with depth. The results indicate that the variation of mean was uniform distribution in the field. According to Amberger (2006) the values of exchangeable Al^{3+} in the studied soil are rated as medium to high. The site is mostly suitable to tea plantation based on the existing literature and other related study.

Electrical conductivity

The Electrical conductivity is expressed as salt concentrations level in the soil and its large amount create high osmotic pressure and impair soil nutrient uptake. Electrical conductivity values of the studied area were 0.0518±0.721 dS/m, 0.0485±0.721 dS/m and 0.0416±0.721 dS/m of topsoil, middle soil and subsoil respectively with c.v of 17.2% (table 6) and it increase with soil depth. The results indicate that the variation of mean of electrical conductivity was uniform distribution in the field and was ranked the soil to be non-saline this is due to its high organic matter. According to Hazelton & Murphy (2007), the soil is rated as non- saline as indicted by its low values of electrical conductivity (<2dS/m). several studies confirm effect of high concentration of salts though it is neglectted for <2 dS/m whereas at 4-8 dS/m affect different crop yield. This implies that the studied soil cannot impose any limitation of EC to the tea growth.

Organic Carbon and Organic matter

The organic carbon content in the studied area was 6.26±0.721 %, 5.75±0.721 % and 3.53±0.721 % of topsoil, middle soil and subsoil respectively with c.v of 13.9% and s.e. (table 7) and was ranked as medium to high OC content corresponding to OM which is high with the values of 10.79±1.244%, 9.91±1.244% and 6.08±1.244% of topsoil, middle soil and subsoil respectively with c.v of 13.9% (table 7) when matched with the critical levels (low when the organic matter is < 3.1%, medium 3.1-4.5% and high when it is 4.6-19%) (Borah et al., 2009) and decrease with soil depth. The results of the studied soil are in line with the soil organic matter required by tea growth as the tea grow well in the soil with an organic matter greater than 2% (Approach, Jayasinghe, & Kumar, 2019). The high organic carbon observed was attributed to the fallow on the studied area and the vegetation on the field as it has been more than 10 years without cultivating on the site but before they use to cultivate the *Thitonia diversiforia* used as malaria cure medicine. In the studied soil there is a decrease of quantity of organic matter with depth. The fallow on the site allows the accumulation of the organic carbon from the hair roots dead and increase the microbial activity (Ferguson, Hergert, & Specialists, 2009).

Yüksek, Ceyhun Göl, Yüksek, & Yüksel (2009) observed high OM concentration in uncultivated topsoil since week disturbance enhance higher accumulation of organic materials on surface due to the roots decomposition which increase OM in non-tilled treatments. The large quantity of OM in the soil was due to the accumulation of large quantity of plant residues in the soil and to the substantial amount of rainfall of about 1364mm/year and warm temperature of 18.6^{o}C such good climatic condition is favorable for rapidly organic materials decomposition. The soil with high organic matter has improved soil structure and high capacity of plant nutrients such as nitrogen, phosphorus and potassium. It also responsible for high water holding capacity and high infiltration rate.

Table 7: Ferralsol chemical properties (pH, EC and exchangeable acidity) in Gisakura tea plantation in 2019

Soil depth	OC (%)	OM (%)	TN (%)	C/N	TP (%)	Av. P (ppm)
0-20	6.26	10.79	0.0709	88.49	0.02063	6.45
20-40	5.75	9.91	0.0661	87.2	0.02125	5.35
40-60	3.53	6.08	0.0362	99.14	0.02	3.85
s.e (5% level)	0.721	1.244	0.00848	10.819	0.003385	0.694
l.s.d	2.099	3.619	0.02715	14.495	0.006587	3.8
SD (%)	13.9	13.9	14.7	11.8	16.4	13.3

Total nitrogen and C/N ratio

The total nitrogen content of soil studied was 0.0709±0.00848%, 0.0661±0.00848% and 0.0362±0.00848% of topsoil, middle soil and subsoil respectively with c.v of 14.7% (table 7) and it decrease with the depth this is due to high organic matter content and the acidity of soil as we know that nitrogen in soil is exist in organic form. The total Nitrogen content in the studied soil were considered very low to low when matched with the critical levels of total Nitrogen (very low when is less than 0.05%, low when it is 0.05-0.15%, medium when it is 0.15-0.25%, high when it is 0.25-0.5% and very high when it is greater than 0.5%) (Hazelton & Murphy, 2007). The total Nitrogen observed is attributed to the low pH which restricts microbial activities. For the pH values of about 5.5 and below, bacterial activity is reduced and decomposition of organic matter is significantly retarded.

The C/N ratio values was 88.49, 87.2 and 99.14 of topsoil, middle soil and subsoil respectively in the studied area. The C/N ratio measures the relative nitrogen content of organic materials. According to Mbaga et al. (2017), if the soil has a C/N ratio which is greater than 25, the decomposition of organic material is slows this will cause the nitrogen immobilization where nitrogen will be tied up in organisms decomposing the organic material and will not be available to any crops and the organic material is raw and is unlikely to break down quickly (Ping et al., 2014; Nuwategeka et al., 2016). During tea production, there is high nutrient requirement and the large nutrients percentage are found in the harvestable portions of tea. The most important nutrients like nitrogen are required in large for tea. 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).

Total and available phosphorus

The total phosphorus in the studied soil was 0.02063±0.003385%, 0.02125±0.003385% and 0.02±0.003385% of topsoil, middle soil and subsoil respectively with c.v of 16.4% (table 7) and was rated medium when matched with the standard values for total phosphorous in soil (Horneck et al., 2011; Karuma et al., 2015). Available phosphorus in the studied soils was 6.45±0.694ppm, 5.35±0.694ppm and 3.85±0.694ppm of topsoil, middle soil and subsoil respectively with c.v of 13.3% and was deficient. According to Ping et al. (2014), an available phosphorous level of 7-15 mg/kg is generally considered as the critical level on which deficiency symptoms of P are likely to occur in several crops. These low values of available phosphorous in soil was due to low pH of the soil which interfere the decomposition process resulting to the soil available nutrients (Sultana et al., 2014). According to Molindo (2009), aluminium and iron react with phosphate ions to make compounds and this lead to nutrient deficiency to plant. Application of organic materials in tea plantation has shown a great potential to improve soil phosphorous as well as improving soil fertility status.

4.2 Potentials and limitations of the studied soil for the tea plantation

Potentials and limitations of Gisakura tea plantation are presented by both soil properties (physical and chemical properties). The high altitude of the studied area has slope which is very steep (>60%) posing limitations of mechanized agriculture and high risk of soil erosion and for it protection is better to use the perennial crop as tea. The studied soils are deep with above 60 cm and well drained where tea can be established and grow well. The studied area does not show any limitations like surface stoniness, sealing/crusting, flooding which would have otherwise prompted the selection of other land uses apart from tea production. This area is dominated by textures, which are sandy loam and loamy sand, this textures are favorable for the tea production. Soil acidity is an important parameter, which affect the growth of tea as it controls the aluminium availability on tea, and the studied soil is acidic which is good for tea growth. The organic matter of the studied soil does not show any limitation for tea growth as it high and tea grow well in the soil with high organic matter content. The soil of the studied area shows some limitation of having low total nitrogen, low total phosphorous and low available phosphorous. In fact, the soil is strongly acidic and need some amendment to rise the pH.

CHAPTER V: CONLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The analysis of land suitability for tea is important information to improve the tea sector in Rwanda. According to the study findings the physical properties of the studied soil were in line with the physical requirements for tea growth. In fact, the studied soil has high sand particles content and high aggregate stability which assigned a well internal drainage. The soil bulk density was low therefore allows the root penetration and the optimum soil water retention capacity release the relatively needed water for tea growth. The chemical properties show some limitation on tea growth. The soil pH was strongly acidic with high exchangeable acidity, which restricted the availability of the nutrients, as the condition might not be favorable to nutrient avilability. The soil was non-saline with a low electrical conductivity and there was a medium to high organic carbon and high organic matter contents which is the best condition for tea grow. The nutrients like total nitrogen, total phosphorous and available phosphorous were low and would be deficient to tea plants this is due to the very acidic condition of studied ferralsol, in fact, the soil was fallowed for long period this has reduce the mineralization of nutrients as there was no addition of fertilizer, and it might also due to parent material from which the soil was formed. The potential of studied soil shows that tea is moderated suitable in area because of limitation on the availability of nutrients therefore, the remedial measures will help in improving soil nutrients availability.

5.2 Recommendations

From this study findings, the following recommendation are recommended:

- For the improvement of production, the soil acidity could be improved to the required standard to allow availability of nutrients using a low quantity of lime and organic manure.
- As there are low Nitrogen and phosphorous, use of organic manure combined with inorganic fertilizers to provide the optimal level of nutrients.
- Father research should be conducted to studied biological properties and other
- Use of agroforestry trees as they will improve soil fertility

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Appendix

Appendix 1: Selected physical properties of the studied soil

Texture								
			Particle size distribution					
Sampling area	**S/NO**	**Depth (cm)**	**% Sand**	**% Clay**	**% Silt**	**Textural classes**	**Aggregate stability**	**Bulk density g/cm^3**
Upland	S1	0-20	78	7.4	14.6	Sandy loam	0.63	0.260353902
		20-40	82	9.4	8.6	Loamy sand	0.58	
		40-60	82	10.6	7.4	Loamy sand	0.53	
	S2	0-20	83	7	10	Loamy sand	0.69	0.223039336
		20-40	85	7	8	Loamy sand	0.67	
		40-60	85	9	6	Loamy sand	0.63	
	S3	0-20	78	6	16	Loamy sand	0.70	0.219647103
		20-40	80	7	13	Loamy sand	0.69	
		40-60	82	10	8	Loamy sand	0.68	
	S4	0-20	86	4	10	Loamy sand	0.66	0.252721377
		20-40	81.4	9.6	9	Loamy sand	0.66	
		40-60	84	10	6	Loamy sand	0.67	
Lowland	S1	0-20	79	7.8	13.2	Sandy loam	0.57	0.294841606
		20-40	77	11	12	Sandy loam	0.56	
		40-60	79	12	9	Sandy loam	0.54	
	S2	0-20	79	8.6	12.4	Sandy loam	0.60	0.287209081
		20-40	81	9	10	Loamy sand	0.60	
		40-60	81	10	9	Loamy sand	0.63	
	S3	0-20	80	7	13	Loamy sand	0.65	0.258092413
		20-40	82	6	12	Loamy sand	0.59	
		40-60	81	8.4	10.6	Loamy sand	0.55	
	S4	0-20	85	5.8	9.2	Loamy sand	0.66	0.248198399
		20-40	83.6	8	8.4	Loamy sand	0.63	
		40-60	82	10	8	Loamy sand	0.69	

Appendix 2: Selected chemical properties of the studied soil

						Exchangeable Acidity	
Sampling area	**S/NO**	**Depth (cm)**	**pH water**	**pH KCl**	**EC (dS/m)**	**exch. H^+** (cmol/kg)	**exch. Al^{3+} (**cmol/kg)
Upland	S1	0-20	4.83	4.15	0.04904	0.32	5.36
		20-40	4.46	4.11	0.04172	0.08	5.84
		40-60	4.44	3.93	0.03982	0.08	6.08
	S2	0-20	4.44	4.18	0.04363	1.12	5.04
		20-40	4.42	4.16	0.04172	1.2	5.44
		40-60	4.4	3.99	0.03954	1.52	6.32
	S3	0-20	4.51	4.21	0.0453	0.48	5.44
		20-40	4.42	4.15	0.04766	1.12	6.56
		40-60	4.51	3.96	0.03655	0.96	6.96
	S4	0-20	4.55	4.21	0.0465	0.56	5.52
		20-40	4.49	4.21	0.04911	0.56	5.6
		40-60	4.51	4.04	0.03525	1.76	6.64
Lowland	S1	0-20	4.15	4.04	0.04922	0.24	6.32
		20-40	4.02	4.02	0.04505	0.32	6.48
		40-60	3.96	3.9	0.04819	0.16	6.8
	S2	0-20	4.1	3.91	0.06942	0.88	7.52
		20-40	3.9	3.83	0.0661	0.64	8.64
		40-60	3.88	3.98	0.06306	1.52	9.92
	S3	0-20	4.49	3.99	0.05574	1.36	6.16
		20-40	4.44	3.94	0.05482	1.04	6.96
		40-60	4.45	3.84	0.03629	2.16	7.12
	S4	0-20	4.21	4.1	0.05543	1.2	6.64
		20-40	4.19	4.1	0.04172	1.84	7.6
		40-60	4.18	3.99	0.03378	1.12	8.96

Appendix 3: Selected chemical properties of the studied soil

Sampling area	S/NO	Depth (cm)	% OC	% OM	% TN	C/N	% TP	ppm AV.P
Upland	S1	0-20	5.990076	10.32689	0.059744	100.26	0.015	4
		20-40	4.365649	7.526379	0.053505	81.59	0.025	3.6
		40-60	2.132061	3.675673	0.020936	101.84	0.015	3.2
	S2	0-20	6.396183	11.02702	0.076176	83.97	0.015	4.8
		20-40	5.787023	9.976827	0.068834	84.07	0.025	4
		40-60	2.538168	4.375802	0.029741	85.34	0.02	3.2
	S3	0-20	6.49771	11.20205	0.077157	84.21	0.02	4.4
		20-40	6.294656	10.85199	0.075934	82.90	0.015	2.8
		40-60	3.553435	6.126122	0.031312	113.48	0.02	3.2
	S4	0-20	6.80229	11.72715	0.075866	89.66	0.025	5.2
		20-40	6.396183	11.02702	0.070429	90.82	0.02	4.8
		40-60	3.858015	6.651218	0.036807	104.82	0.02	3.2
Lowland	S1	0-20	5.177863	8.926635	0.066988	77.30	0.025	7.6
		20-40	4.873282	8.401539	0.06708	72.65	0.02	6
		40-60	3.147328	5.425994	0.035807	87.90	0.015	3.2
	S2	0-20	6.091603	10.50192	0.06536	93.20	0.02	8.8
		20-40	5.990076	10.32689	0.062112	96.44	0.025	8
		40-60	3.654962	6.301154	0.033178	110.16	0.025	4.8
	S3	0-20	6.396183	11.02702	0.069961	91.43	0.02	8.8
		20-40	5.990076	10.32689	0.070937	84.44	0.025	6.4
		40-60	4.974809	8.576571	0.062479	79.62	0.02	4.8
	S4	0-20	6.700763	11.55212	0.076253	87.88	0.025	8
		20-40	6.294656	10.85199	0.060116	104.71	0.02	7.2
		40-60	4.365649	7.526379	0.039716	109.92	0.015	5.2