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Contribution of agrisilviculture system in improving soil quality in gishwati – mukura landscape,case of satinsyi river watershed in western midhighland of Rwanda

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ABSTRACT

Adoption of agroforestry system is believed to improve soil quality in Rwanda as the quality have been degraded for a long time due to natural and man-made activities. The undertaken study was to assess the contribution of agrisilviculture on soil quality in case of of main river satinsyi watershed in western midhighland of Rwanda. Stratified soil sampling method has been used to collect samples along a toposequence on four subwatersheds (Nyamakanda, Satinstyi, Rustiro and Rucanzongera) and a total of 27 composite samples analyzed in the laboratory. The soils in the study area were deep (>90cm) and well drained (Sandy loam). The upper, middle and lower slopes bulk densities were low ranging from 0.88 to 1.29 g/cm^3; 0.89 to 1.19 g/cm^{3}0.88 to 1.132 g/cm^3 in the lower slope. The sand content rated as very high and ranged from 68 to 82 % in the upper land; from 72 to 84% in the middle land and from 72 to 66 % in lower land, respectively. The clay and silt content was low compared to sand ranging from 8 to 14 % for clay and 6 to 24% silt. The porosity was high ranging 51.36 % in the upper land; 52.55 to 63.54 % in the middle and from 50.47 to 57.35 % in the lower land slope. The soils reaction along all subwatersheds rivers was strongly acid ranging from 4.5-5.1 in the upper slope; 4.38-4.9 in the middle slope and 4.35-4.97 in the lower slope. The organic content in the upper middle slopes were rated as medium ranging from 1.38 to 2.47%, corresponding to 2.38 and 4.26% and 1.33 to 2.47% corresponding to 2,29 and 4.26 % OM respectively. The study sites showed a relatively high amount of available phosphorus ranging between 9.78 and 19.69 in the upper slope; 12.16 and 23.21ppm in the middle slope and 12.58 and 25.31 in the lower slope. Rucanzongera subwatershed seems to have high amount of available phosphorus than the rest. Also, available P is increasing downward the slope the upper, middle and lower slopes showed medium to high levels of nitrate ranging from 19.15 to 38.34 ;16.97 to 32.75 and 18.24 to 30.28 respectively**.** Generally**,** the distribution of the soil properties along the topo sequencein 3sub watersheds (Nyamakanda, Satinsyi and Rustiro sub catchments) had indicated that most of the soil properties increased or decreased along a topo sequence whereas Rucanzongera sub watershed doesn’t show any trends of increasing or decreasing which show the good contribution of agroforestry on soil quality.

DECLARATION

I, Emerthe Uwimbabazi, do hereby declare to the Senate of University of Rwanda, that this dissertation is my own original work undertaken within the period of registration and that it has neither been submitted nor being submitted in any other university

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Emerthe UWIMBABAZI Date
(MSc. Candidate)

The above declaration is confirmed by:

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Dr. RUKANGANAMBARA Hamudu Date
(Supervisor)

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DEDICATION

I wish to dedicate this work to my parents Joseph NYABYENDA and Berancilla MUKANGANGO, to my husband Dr. Schadrack NTIRENGANYA, to my son Lucas Brice HIRWA and to my brothers and sisters.

I dedicated this dissertation.

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Al	Aluminium
C/N	Carbon to Nitrogen ratio
Ca	Calcium
CEC	Cation Exchange Capacity
cm	centimetre
cmol(+)/kg	Centimol charge per kilogramme of soil
e.g.	For example
EC	Electrical conductivity
et al.	and others
FAO	Food and Agricultural Organization of the United Nations
Fe	Iron
g	gramme
ha	Hectare
K	Potassium
kg	kilogramme
m	metre
m.a.s.l.	metre above sea level
Mg	Magnesium
mm	millimetre
Mn	Manganese
Na	Sodium
NISR	National Institute of Statistics of Rwanda
^{o}C	Degrees Celsius
OC	Organic carbon
OM	Organic matter
P	Phosphorus
pH	negative logarithm of hydrogen ion concentration
TN	Total Nitrogen
UR	University of Rwanda
SSA:	Sub-Sahara Africa
SOM:	Soil Organic Matter

CHAPTER I. Introduction

1.1.Background information

Land degradation is a major problem in sub-Sahara Africa (SSA). Food shortage is the main issue in the region as population is growing *(Tully et al*.,2015).The main causes are pedological causes, morphological causes (altitude and rainfall);climatic variability; population pressure which led to over cultivation and increased erosion (Adolfsson, 2008; Tully *et al*.,2015).

Arable farming is the main source of income for more than 65% of the people in SSA; however, land degradation and an unavailability of fertilizer for production and remediation purposes has led to food insecurity (Pasley *et al*., 2019; AGRA, 2018).These situations have led many researchers to search new and better management strategies such as agrisilviculture. The role of agrisilviculture has been long seen to be a benefit since its introduction as scientific science. (Dollinger & Jose, 2018 and Mulyono, *et al*., 2019). It is a system where both forest and agricultural resources are integrated and managed on the same landscape (Paudel*et al*.,2012and Dollinger & Jose, 2018). This system improves soil quality trough controlling erosion, maintaining soil organic matter(SOM), maintaining soil physical properties, increasing nitrogen fixation, promote efficient nutrient cycling, reduce soil toxicity, increase soil nutrient inputs, promote desirable soil fauna activities and increase soil water availability(Sharma, 2008; Ndalama & Missanjo, 2015).

Soil quality is the ability of soil to sustain biological activity, promote environmental quality , plant and animal health as well (Kime, 2017). In assessing the quality of soil, multiple soil parameters representing chemical, physical, and biological characteristics must be analyzed (Kime, 2017).Based on literature studies, soil quality englobe the capability of the soil to carry out different functions (Karlen *et al*., 1997). According to Seybold et al., (2018), soil function include production of biomass; storage, filter buffer, and detoxify organic and inorganic materials ; transformation of nutrients, substances and water,; biodiversity restoration and physical environment for human activities. it is also source of raw material and it is acting as geological heritage (De La Rosa & Sobral, 2008).

Rwanda is a small land locked country of 26,000 km^2 and agricultural is the main activity. In Rwanda, land shortage coupled with low organic matter and low fertility has made all farmers to be unsecured regarding food availability. This is because of fast oxidation of organic matter, leaching of nutrients, erosion, and continuous cultivation without replenishment. Human pressure in recent decades has changed the land use of Gishwati – Mukura landscape from 250,000 ha to 28,000 ha in 1980 which was consequently in ecological disasters (Rema *et al*., 2014). The sustainable use and management of fragile Gishwati – Mukura landscape has different economic and ecological importance. This pushed land users to adopt different systems to reduce land degradation such as agroforestry, agro horticulture and silvopastoral. These land use systems showed high importance in sustaining soil fertility and its quality (Nair, 2011; Sharma, 2008).

1.2.Problem statement

Soil degradation together with soil infertility have long been seen as critical problems in population of Rwanda (Project, Land, & In, 2007 ; MINIRENA, 2016). The main causes are nutrient depletion , loss of soil organic matter (SOM) (Project, Land, & In, 2007 ; MINIRENA, 2016;Environment & (REMA, 2017).

Gishwati and Mukura areas are no exception in terms of land degradation. Due to deforestation and other human activities, the area suffered from severe erosion, landslide and floods which have led to degradation of its soil quality in particular soil fertility (Tharcisse, 2014). The major causes are population density (500 people/km^2) coupled with high rainfall and steep slopes and various human activities (massive deforestation, over cultivation), which led to increased rate of erosion, hence high sediment loads in the rivers. Also high rainfall with steep slope of the area resulted into flooding and landslide (Busokeye, 2014)

The government of Rwanda has currently committed to conserve the natural forests of Gishwati - Mukura forest and its biodiversity through improvement of soil quality for the sake of welfare of its population(MINIRENA, 2016). For that purpose, Rwanda Environment Management Authority through its project called "Landscape approach to forest restoration and conservation (LAFREC)" has objective of restoration of the highly degraded landscape of Gishwati- Mukura for environmental and economic enhancement of both forest. Although, agroforestry system have been seen as a way of sustaining productivity (Rousseau, Deheuvels, Rodriguez Arias, & Somarriba, 2012).Little information is available in literature review for transect between Gishwati- Mukura landscapes. The present work was to assess the contribution of agrisilviculture (LAFREC project) on soil quality in Gishwati-Mukura landscape.

1.3.Objective of the study

1.3.1. Overall objective

The general objective of this study was to evaluate LAFREC Project's contribution in improving soil quality under agrisilviculture land use system in Gishwati-Mukura landscape.

1.3.2. Specific objectives

i. To evaluate the effects of Agrisilviculture system on chemical indicators (soil pH, Electrical conductivity, soil organic carbon, total and mineral N and available P)
ii. To evaluate the effects of Agrisilviculture system on Physical indicators (soil depth, soil texture, bulk density, aggregate stability and porosity),
iii. To evaluate the effects of Agrisilviculture system on biological indicators (Soil organic matter)
iv. To compute Soil Quality Index (SQI) for Gishwati- Mukura landscape

1.4.Research question

i. What is the impact of agrisilviculture system on physical indicators of soil quality in Gishwati-Mukura landscape?

ii. What is the impact of agrisilviculture system on chemical indicators of soil quality in Gishwati-Mukura landscape?

iii. What is the impact of agrisilviculture system on biological indicators of soil quality in Gishwati-Mukura landscape?

1.5.Research hypothesis

i. Null hypothesis (Ho): There is no impact of agrisilviculture on soil quality in Gishwati – Mukura landscape.

ii. Alternative hypothesis (H1): There is a high significance impact of agrisilviculture on soil quality in Gishwati – Mukura landscape.

CHAPTERII. Literature Review

1.6.2.1. Concept and definition of soil quality

2.1.1 Definition

The quality of soil explained by its ability to function within natural or managed ecosystem, to improve plant and animal productivity to support human health (Karlen *et al*., 1997). It indicates the soil's fitness to serve as promoting plant and animal productivity, regulating the movement of water and improving the health of human being (Baginetas, 1998).less infertile soil does not produce good yield of crops therefore managing soil in proper manner and maintaining its fertility is a main concern for better future (Hartemink, 2005).

2.2.2. Soil quality indicators

Table. 1. Soil physical chemical indicators as described. Nsengimana *et al.,* (2018)**.**

Indicators	**Explanations**
Physical properties	
Particle size distribution (Texture)	The capacity of retention and transport of material and to assess level of erosion.
Soil depth	Rooting condition and level of soil erosion
Bulk density and infiltration	Compaction of soil and level of leaching of nutrients
Water holding characterics curves	The of water retention, productivity and soil erosion
Soil aggregate	Soil resistance to erosion and soil management effect
Chemical properties	
Soil organic carbon	Soil fertility status, stability and extent of soil erosion
Soil pH	Plant nutrient availability
Electrical Conductivity (EC)	Salinity and level of water infiltration
Available Nitrogen, Phosphorus and Potassium.	Available nutrients for crop uptake
Biological properties	
Microbial biomass nitrogen and carbon	Microbial catalytic potential, respiratory for carbon and nitrogen and the effect of of organic matter on land management
Porosity, moisture content and temperature	For microbial activity, process modelling and estimate of biomass activity.
Metabolic quotient	For soil microbial community
Microbial functional group	Levels of phosphate solubulizer and diazotrophic nitrifying and ammonifying bacteria

2.2.2.1. Brief description of Chemical indicators

There are a lot factors that control soil properties in the ecosystem, soil physical-chemical and biological properties normally change across a short distance within a few hectares of agricultural fields(Society, 2019)

Soil pH

pH is the measurement of acidity or alkalinity that give an indication of the hydrogen ion and hydroxyl ion activity in water solution. High values of hydrogen means more acidity, Acidic or alkaline soils affect microbial activity; availability of nutrients for plant uptake and Aluminium toxicity (Murphy and Hazalton, 2007). We normally test soil pH in water and in Kcl because the difference between pHkcl and water gives an idea on the potential acidity and this test in Kcl is considered more reliable when assessing acidity. Most crops grow well in the PH ranging between 6 and 7.5 and liming is a remediation for soil acidity (Marx E.S., Hart J., 1999)

Electrical conductivity

The electrical conductivity measures the soluble salts in the soil extract and this is done to see how salts affect plant growth. The EC is controlled by soil texture and concentration of dissolved salts in soil solution. A high EC values indicate a high salinity level in the soil and it has been reported that EC below dS/m is negligible whereas at EC of 4dS/m, the growth of many crops are restricted except for tolerant crop in which EC may reach up to 8 and 16dS/m (Ndyeshumba, 2015)

Organic carbon and organic matter

The organic carbon in the soils varies with soil texture , Cation Exchange Capacity(CEC) and rainfall variability (Ndyeshumba, 2015). Soil with lower CEC tends to have lower organic carbon whereas higher rainfall (> 500 mm/year) with fine texture will have higher OC levels. Improving organic matter will increase the soil CEC and nutrients retention capacity of soils. OC is more closely linked with soil health than yield. Under long term pasture or where water logging has allowed building OC, there is high value of OC and this can be a sign of low levels of biological activity due to acidity problem and water logging.

(Dollinger & Jose, 2018)

Total nitrogen, available nitrogen and C/N ratio

Nitrogen is among primary constituent of plant minerals and to be taken by plant, it have to be in the mineralized forms (Ammonia and Nitrate)(Marx E.S., Hart J., 1999).Total Nitrogen (TN) measures the total amount of nitrogen present in the soil but still unavailable to plant. When we have high amount of ammonium and nitrate, it indicates reducing conditions and those available forms can leach down, that is why deep testing is required to reduce errors and get good results. The desired ranges of ammonium and nitrate in the agricultural soil are 2-10 ppm and 10-50 ppm respectively (Marx E.S., Hart J., 1999)

Exchangeable cations and cation exchangeable capacity

Cation Exchange Capacity (CEC) is the capacity of soil to retain and release cations in the soils is the measure of soil capacity to retain and release cations (Ca, K, Na and Mg). its determination can be important in predicting behavior of pesticides and other chemicals in the soils(Behera *et al*., 2016). It is associated with exchangeable bases and is affected by soil texture, soil pH and amount of organic matter. The difference between CEC and effective CEC is that for CEC, sum up exchangeable bases while for ECEC, you add exchangeable bases plus exchangeable acidity (H+ and Al 3+). Desirable range of CEC IN AGRICULTURAL SOILS RANGE BETWEEN 5 AND 25 cmol+/kg (Aşkın, Kızılkaya, & Yılmaz, 2012). The CEC affect soil structure, nutrient availability, soil Ph, and soil reactions for fertilizer recommendations

2.2.3. Soil indicators integration and assessment (Soil quality index)

The basic concept of soil is important to deal with before dealing with soil quality assessment. It can be monitored using the concept "indicators" and those indicators can be classified as physical, chemical and biological indicators. The overall soil quality may be assessed through measuring changes in these indicators (Sharma, 2016).

Computation of soil quality index

Soil quality index value was calculated by the formula as describe Bajracharya *et al*. (2006)

SQI: $[(a*R_{STC}) + (b*R_{pH}) + (c+R_{OC}) +(d+R_{NPK})]$

Where,

SQI: Soil quality index

$R_{STC:}$ Ranking values for soil textural class

RpH: Ranking values for soil pH

R_{OC}: ranking values for soil organic carbon

R_{NPK}: Ranking values for Nitrogen, Potassium and Phosphorus

a: 0.2, b:0.1, c: 0.4, d:0.3

Scoring method

This method developed by NARC (1993)

			Ranking values		
Parameters	0.2	0.4	0.6	0.8	1
Soil textural class	S,C	CL,SL, SiC	Si, LS	L, SiLSL,	SiCL, SC
Soil Ph	<4	4-4.9	5-5.9	6-6.4	6.5 -7.5
SOC	<0.5	0.6-1	1.1 -2	2.1 - 4	> 4
NPK	low	Moderate to low	moderate	Moderate to high	high
SQI	Very poor	Poor	Fair	Good	Best

C: Clay Ssand, CL: clay loam, SC: Sandy clay, SiC: Silt clay, Si: Silt, LS: loam sand, SiL Silt loam, SL: sandyloam LS: loam sand SiL: Siltloam, SL: sandy loam, SiCl: silt clay loam, SCL: Sandy clay loam

2.2.4. Soil quality degradation

Simply, soil is degraded when its properties (physical-chemical and biological) are deteriorated such as loss of organic matter, salinity problem, acidity or alkalinity, toxicity, erosion and decreased soil fertility (Alam, 2014). Soil degradation occurs when there is a pressure on land trying find food, fodder and fiber die to growth of population (Misra, 2018). According to Aulakh & Sidhu (2016), different human activities such removal of natural vegetation, overgrazing and activities related to agriculture such as irrigation and fertilization accelerate soil degradation through increased salinization, flooding, drought, waterlogging and erosion. Another cause of soil degradation may be also global warming which led to emission of greenhouse gases to the atmosphere (Ndalama & Missanjo, 2015). Land use systems, soil types and topography are the dependent factors when assessing the rate of soil quality (Triantafyllidis, Kosma, & Patakas, 2018).

2.2.5. Agroforestry: Agrisilviculture

Agroforestry has been practiced for thousands of years but it is being not known as a science., the term 'agroforestry' was first coined in 1977"(Smith, 2010). Globally, Agroforestry is a system where wood perennials are grown in association with plants or livestock on the same land unit (Lundgren, 1982; Nair, 1993; Gold and Garrett, 2009; Smith, 2010).the main issue here is the concept of integrating both forestry and agriculture systems.

It is a management practice that optimizes limited resources through various benefits, including combination of different components within a landscape unit. Additional income sources, increased and diversified production, improved water quality, and enhanced habitat for humans and animal life are provided by the interactions in agroforestry systems. There are other environmental benefits of agroforestry practices including maintenance and improvement of soil quality through increasing organic matter, carbon sequestration and nitrogen fixation. Agroforestry systems is subdivided into different component such as agrisiliviculture (fig. 2), silvopastoral (tree and animals) and agro-silvopastoral (trees, crops and animals).

Figure 1: Potatoes growing in alley system

Role of agroforestry

It plays a role in increasing soil fertility and soil quality in different ways as described by Choudhury(2002); Sharma (2008);Cornwell (2014); Kime(2017)and Mulyono *et al*.(2019).

- It controls soil erosion: Hedgerow intercropping or barrier hedges are the most effective means of erosion control. Those barriers act as contour planted and cover for erosion control on steep slope to reduce runoff and improve soil infiltration

- It sustains soil organic matter: this is through the way agroforestry reduce erosion wich may reduce the loss of organic matter. This organic matter will play an important role in in maintaining soil fertility (soil physical properties) CEC and release of nutrients
- Nitrogen fixation: Agroforestry systems add nitrogen in the soil through atmospheric nitrogen fixation
- Efficient nutrient cycling: In the soil, plant nutrients are in condition of continuous and dynamic transfer (means nutrients from the soils are taken up by plant and used for metabolic activities.
- Reduce soil toxicities and promote desired soil fauna activity

2.2.6. Watershed management description (Mukura-Gishwati landscape description)

According to Tuyishimire (2017), in Gishwati-Mukura landscape there was a need to protect rivers and watersheds. LAFREC planned to implement two sub-programs:

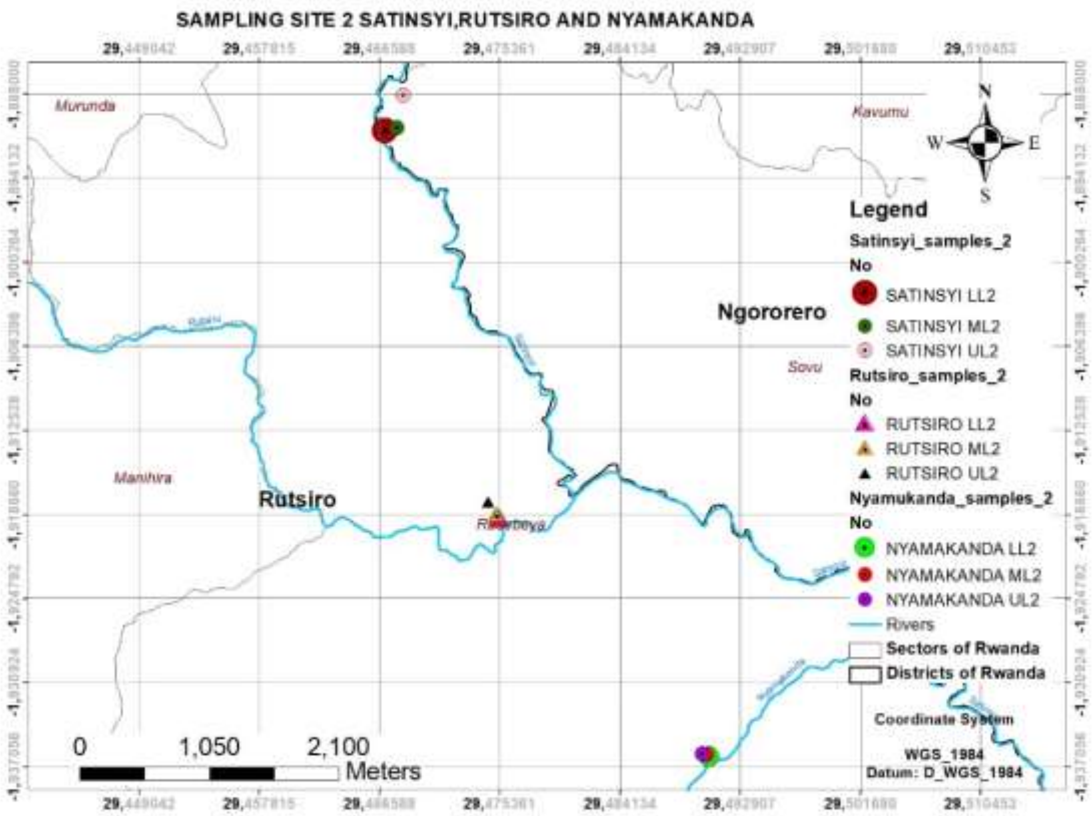
The river banks protection sub-programme, targeted the plantation of trees especially bamboo of 10 m strips on both side of each river. Sixty-six ha of river banks for 4 rivers (Rutsiro, Nyamakanda, Satinsyi and Rucanzogera) had to be protected. Agroforestry tree species such as *Mimosa scabrella, Acacia angustissima, Leucaena diversifolia, Tephrosia vogelii, Alnus acuminata, Podocarpus falcatus, Avocadovar Hass, Grevillea robusta, Dombeya torrida* and *Croton megalocarpus* covering an area approximately 995 ha and the distance of 150 m from the river bank protection buffer should be protected in this second sub-programme. Objective of these sub-programmes was the protection of rivers and watersheds which influence positively soil quality by minimizing soil degradation and soil and water pollution.

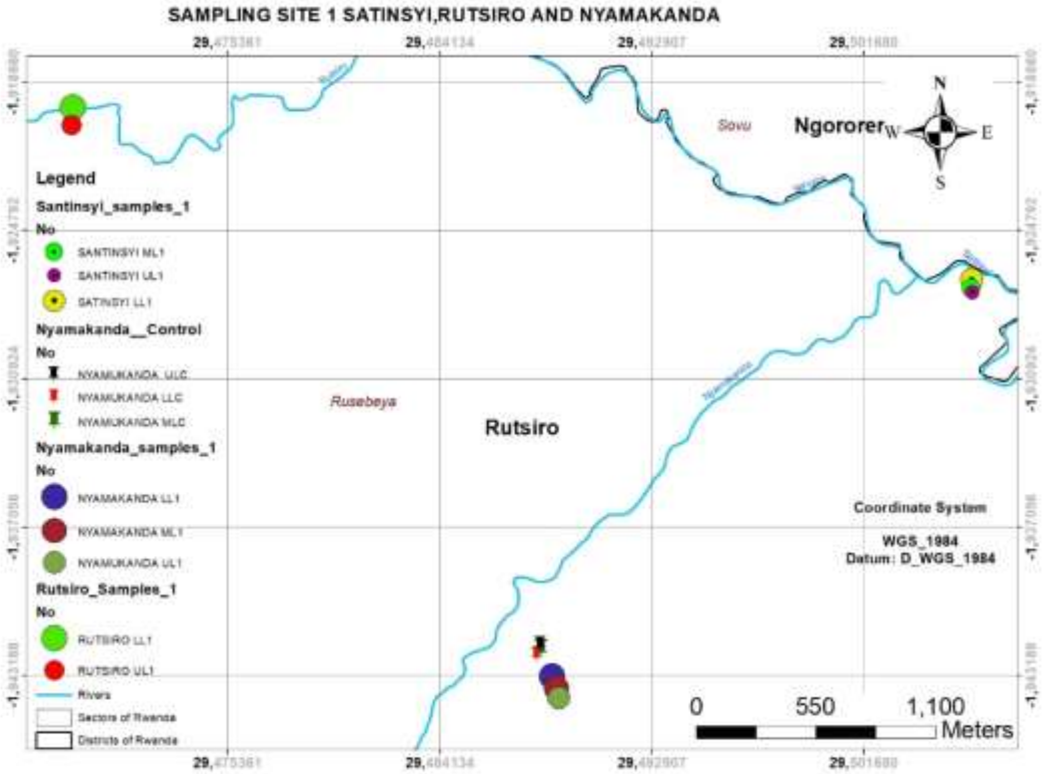
CHAPTERIII. Material and methods

3.1. Description of the study area

The study undertaken in Gishwati- Mukura landscape which is located in the North-Western part of Rwanda in Congo Nile Watershed Divide agro ecological zone (CNWD), in the Albertine lift and Congo-Nile divide regions at (1° 49´ S, 29° 22´ E) as presented in Figure 1. The study areaincludesparts of 4 districts (Rustiro, Rubavu in the west and Ngororero and Nyabihu in the East). Gishwati reserve includes parts of all the 4 Districts but Mukura include only part of Rutsiro and Ngororero (MINIRENA, 2010).

Figure 1. Map





1.7.

1.8.The climate is tropical. The average temperature ranges between 20º and 24ºc with the mean annual rainfall between 1500-1600 mm/year and elevation of 2000 to 3000 m above sea level (RDB and REMA, 2017). The lower altitude is 1900m and the upper of the mountain chain surpass an altitude of 2500m. in the south, annual rainfall is between 1400 and 1800 mm whereas in the north it varies between 1300 and 1500 mm/year (Verdoodt and Van Ranst, 2003a).The geology of the study is largely composed by Precambrian metamorphic complexes of Butare including alternation of granite, gneissic granite, quartzitic and mica-schistose meta sediments, amphiboles and some mylonites (Theunissen *et al.*, 1991). The soils have whitish, reddish and black color with good structure. The area is dominated by saprolite (highly weathered soils), umbrisols (due to decomposition of organic material), lixisol, ferrsols and alisols.

1.9.Table 2. Salient characteristics of the studied soils

Catchments	AEZs[1]	Altitude m. a.s.l.	Lithology	Landform	Land use/vegetation	STR[2]	SMR[3]
Nyamakanda control	CNWD		Granite/shell/feldspars	Mountainous	No LAFREC intervention	Isohyperthermic	Udic
Satinstyi	CNWD		As above	Mountainous	Agriculture/ Sweet potatoes	Isohyperthermic	Udic
Rustiro	CNWD		As above	Mountainous	Agriculture/Wheat, Irish potatoes	Isohyperthermic	Udic
Nyamakanda	CNWD		As above	Mountainous	Agriculture/Tomarillo	Isohyperthermic	Udic
Rucanzongera	CNWD					Isohyperthermic	Udic

[1)] **AEZs:** Agro-Ecological Zones: CNWD: Congo Nile Watershed Divide, the fifth largest agro-ecological zone,

1) AEZs: Agro Ecological zones: CNWD: Congo Nile Watershed Divide occupying the highland area of Rwanda. [2)]STR: Soil Temperature Regime

[3)]SMR: Soil moisture Regime

3.2. Study design

A reconnaissance survey and transect techniques were carried out to locate 4 catchments rivers (Nyamakanda, Satinstyi, Rustiro, Rucanzongera) plus one transect that will be used as a control (no LAFREC intervention). On each catchment, soil was taken along a toposequence with respect to physiographic positions namely upper slope, middle slope and lower slope. On each catchment, three sampling points will be marked such that one will be at the lower (closest to the river) side, the other at the mid slope while the third will be at the upper side of the slope. This setting will be applied to the both sides of a river, leading to a total number of 8 transects and 27 sampling points.

3.3 Soil sampling

The method used to collect soil samples is Y structure sampling to make one composite sample. The soils are inherently variable in short distance and along a toposequence. Therefore, soil sample was taken as a composite of several subsample for the same crop field and along a topo sequence (Upper, Middle and lower slopes). From each sampling point, disturbed and undisturbed composite samples were taken along a toposequence in both sides of each catchment river for physical and chemical analysis. In total 27 composites soil samples were taken to a depth of 15 cm, labeled and prepared for analysis.

The laboratory work was done in Research and postgraduate laboratory of soil and plant at University of Rwanda. The collected disturbed soil samples were air dried and ground to pass through a 2 and 0.5 mm sieve for analysis. Undisturbed soils were used for determination of Bulk density and soil moisture content. Bulk density was determined by core method (Black and Hartage, 1986). Particle density was determined using the mass of the solid particles and the volume they occupy. From here, the mass of the solid particles was obtained by weighing the solid particles and also the volume was determined from the mass and density of water displaced by the sample (Black and Hartage, 1986). Soil porosity was determined using this formula:

Soil porosity= ((particle density-bulk density)/particle density*100 (NSS, 1990).

Particle size distribution was determined by hydrometer then textural classes were determined using the USDA textural class triangle (USDA, 1975). Soil pH was measured potentiometrically in water and in 1N Kcl at a ratio of 1:2.5 soil water (OKALEBO, 2002). Organic carbon was determined by walkley and black wet oxidation (1934) in modified of (Nelson and Sommers, 1982). Total nitrogen was extracted by sulphiric acid and determined colorimetrical (OKALEBO, 2002). And its available forms (ammonium and nitrate was determined also colorimetrical (OKALEBO.2002). Available Phosphorus was determined using Bray II method ((okalebo,2002) where the reading have been done by spectrophotometer at wavelength of 660nm

3.4. Statistical analysis

In the study, the analysis of variance (ANOVA) used to determine the difference among physiographic positions of the study site. Correlation coefficient was also used to determine the interaction among soil properties.

CHAPTERIV. Results and discussion

4.1. Soil physical properties

Particle size Distribution

Particle size distribution and textural classes of the soils studied are presented in Table 2. The sand content rated as very high and ranged from 68 to 82 % in the upper land; from 72 to 84% in the middle land and from 72 to 66 % in lower land, respectively (Macdonald, 1994) and recorded no significant difference among physiographic positions. The high content of sand is probably induced by parent rock of the study area (granite).The parent material of the sites is mainly composed by granites which have been metamorphosed into gneissic materials. These materials are resistant to chemical weathering but rather susceptible to physical disintegration. There is a decrease in sand content along slope in Rustiro and Nyamakanda subwatersheds (w1and w2) due to washing away of colluvium materials transported downslope (Osujieke & Ezomon, 2017). The rest don't show any trend of decrease or increase with slope positions. Research has shown the low fertility status in coarse textured soils coupled with more than 65% sand and less than 18% clay (Phiri *et al.*,2014).

The clay and silt content was low compared to sand ranging from 8 to 14 % for clay and 6 to 24% silt in study area (Table 3). The ANOVA table showed that the percent clay had a significant difference along a toposequence (Appendix. 2.) Clay may interact with soil organic matter and increase water and nutrient holding capacity (Landon, 1991). Wakindiki and Ben-Hur (2002). This expression shows that soil contain more than 20% clay, it may act as cementing agent and will increase aggregate stability of the soils.

Bulk density

Upper slope bulk densities ranged from 0.88 to 1.29 g/cm3; 0.89 to 1.19 g/cm^3 for middle slope and from 0.88 to 1.32 g/cm^{3}lower slope and had significant difference among physiographic positions. According to Msanya *et al*. (2016), the bulk density was found to be below critical limit (< 1.7 dS/m) for root penetration and these values are within the common range for tropical soils(Murphy and Hazelton, 2007).Therefore, the values suggest that studied soils were not compact hence plant roots can penetrate easily and it cannot pose any physical limitation for the agricultural purposes (Murphy and Hazelton, 2007; Msanya *et al.*, 2016).

Table 3. soil physical properties from selected catchment in Gishwati – Mukura landscape

		Particle size distribution							
		% Sand	**% Clay**	**% Silt**	**Textural classes**	**BD g/cm3**	**Particle density g,cm3**	**% Porosity**	**Aggregate stability**
Upper	Nyamakanda control	68	8	24	Sandy loam	1.29	2.66	51.36	0.19
	Satinstyi w1	72	10	18	Sandy loam	0.98	2.66	63.31	0.26
	Satinstyi w2	72	10	18	Sandy loam	1.26	2.66	55.08	0.21
	Rutsiro w1	82	8	10	Sandy loam	0.98	2.62	51.83	0.35
	rutsiro w2	80	8	12	Sandy loam	1.26	2.66	66.52	0.34
	Nyamakanda W1	82	8	10	Loamy sand	1.17	2.63	55.56	0.32
	Nyamakanda w2	78	10	12	Sandy loam	1.17	2.66	56.06	0.34
	Rucanzongera w1	73	22	4	Sandy clay loam	1.32	2.65	50.29	0.35
	Rucanzongera w2	50	40	10	Sandy clay	1.32	2.69	5.47	0.34
Middle	Nyamakanda control	80	8	12	Loam sand	1.18	2.66	55.47	0.31
	Satinstyi w1	84	10	6	Loam sand	0.89	2.66	66.52	0.31
	Satinstyi w2	78	8	14	Sandy loam	1.19	2.64	54.74	0.29
	Rutsiro w1	78	8	14	Sandy loam	0.97	2.66	63.54	0.37
	rutsiro w2	76	8	16	Sandy loam	1.09	2.67	59.03	0.38
	Nyamakanda W1	72	10	18	Sandy loam	1.19	2.67	55.61	0.32
	Nyamakanda w2	72	10	18	Sandy loam	1.17	2.66	56.06	0.33
	Rucanzongera w1	57	28	15	Sandy clay	1.17	2.65	55.90	0.31
	Rucanzongera w2	68	22	10	Sandy clay loam	0.88	2.70	67.57	0.29
lower	Nyamakanda control	72	10	18	Sandy loam	1.19	2.66	55.08	0.32
	Satinstyi w1	68	14	18	Sandy loam	0.88	2.66	67.08	0.35
	Satinstyi w2	66	16	18	Sandy loam	1.13	2.63	56.86	0.31
	Rutsiro w1	70	16	14	Sandy clay	1.14	2.65	57.04	0.29
	rutsiro w2	68	14	18	Sandy clay	1.32	2.64	50.10	0.37
	Nyamakanda W1	70	14	16	Sandy loam	1.13	2.66	57.35	0.38
	Nyamakanda w2	70	14	16	Sandy loam	1.19	2.66	55.45	0.32
	Rucanzongera w1	69	14	17	Sandy loam	1.09	2.63	58.40	1.00
	Rucanzongera w2	71	15	14	Sandy clay loam	1.26	2.66	52.55	0.35

Porosity

The values of total porosity ranged from 51.36 % in the upper land; 52.55 to 63.54 % in the middle and from 50.47 to 57.35 % in the lower land. Porosity decreases with slope position in Control, Rutsiro w2 and Nyamakanda w1 subwatersheds whereas other subwatersheds don't show any trend of change. The ANOVA table showed that the percent soil porosity had significant difference among physiographic positions. Rutsiro subwatershed (w1 and w2) and Nyamakanda w1 showed high values. This is probably caused by high organic matter from litter decomposition and disturbances of the topsoil due to continuous cultivation. In all catchment, the porosity was > 40%, thus they are not liable to restrict crop growth since they indicate no soil compaction, roots penetration without difficulty, adequate infiltration and aeration; enable soil microorganism activity and water storage within the soil, hence increased productivity (Gachene *et al*., 2003)

Aggregate stability

Aggregate stability is defined as the capability of soil aggregates to resist disintegration when disruptive forces associated with tillage and erosion is applied. The upper slope had the values ranging from 0.19 – 0.35; 0.29 – 0.37 for middle and 0.32 – 1 for lower middle. The aggregate stability decrease downward and had a significant difference among physiographic position. The values rated medium in the study(> 2-5) (Adamu, Mrema, & Msaky, 2015)and this means the large aggregate are more sensitive to management effects on organic matter. And greater amount also suggests better soil quality. When the proportion of large to small aggregates increases, soil quality generally increases. As the sites showed relatively high values, still conservation practices resulting in aggregate stability such as conservation crop rotation, cover crop, pest management may be taken into account (Behera *et al*., 2016)

4.2. Soil chemical properties

Soil pH

The pHwater of the studied soils varies slightly along a toposequence (Table 4). The soils along all the catchment rivers were rated as strongly acid ranging from 4.5-5.1 in the upper slope; 4.38-4.9 in the middle slope and 4.35-4.97 in the middle slope. The ANOVA table showed that there no significant difference among physiographic positions whereas for Phkcl the difference is significant. The acidity of the study area may be due to the increase accumulation of above ground biomass associated with cation uptake in the agroforestry systems since the tree roots abundance in the soils result in high uptake of cations hence lowering the Ph. Also the acidic nature of parent material and abundant rainfall may explain the source of acidity in the area since the sites experience high rainfall which led to cation leaching due to coarse textured soils (Ndyeshumba, 2015).Another cause may probably have induced by acidifying nitrogen fertilizer, nitrate leaching, removal of the bases through crop harvests and the farming practices (McKenzie *et al.,* 2004; Brady and Weil, 2008).In agroforestry system, there is a decomposition of organic matter to organic acids and CO_2 biomass, The lower soil pH in the study may be induce by greater production of liter which undergoes decomposition to form organic acids and CO_2 and this also lower the pH (Jama, Centre, Kwesiga, & Centre, 1997).

The strongly acid reaction influence plant nutrients availability for plant uptake. Under this situation plants can show sign of deficiency even if fertilizers have been applied (Hazelton and Murphy, 2007). Also soil biological activity decrease (it affect legume nodulation and earthworm numbers).Low values below pH < 5.5 have potential to cause toxicity problems (Adamchuk *et al.*, 2005).

Electrical conductivity

Upper land EC ranges between 0.02-0.08 while middle land ranges between 0.04-0.08 and lower land ranges between 0.03-0.09 (table 4) and had no significant difference along a toposequence (appendix 2). All slope positions in the study area showed low values <0.07 which imply infertile soils once coupled with low CEC (Fenton and Helyar, 2007). Also the soils are non-saline as indicated by its low values of electrical conductivity (<1dS/m). Studies have shown that at EC below 2 dS/m, salinity effects are negligible whereas at 4 to 8 dS/m, only tolerant crops may successfully give good yield (Society, 2019). The EC measure the relative salt concentrations and too much salt in the soil can interfere with root function and nutrient uptake which was not observed in this study area (Hodges, 2007). Therefore, the EC of the study area indicate the non saline nature of soils (Landon, 1991).

Table 3. Chemical properties of selected catchments in Gishwati – Mukura landscape

treatment		PHwater	pHkcl	EC (dS/m)	% OC	% OM	% TN	C/N ratio	ppm N-NO3	ppm N-NH4	Av. P (ppm)
Upper land	Nyamakanda	4.28	3.76	0.030	1.38	2.38	0.38	3.63	26.46	1.49	9.78
	Satinsyi w1	4.64	3.86	0.057	1.6	2.75	2.35	0.68	19.15	9.04	12.45
	Satinsyi w2	4.41	3.8	0.030	1.62	2.75	2.36	0.69	26.97	9.04	11.67
	Rustiro w1	4.56	3.91	0.055	1.54	2.66	2.41	0.64	27.39	9.37	12.00
	Rustiro w2	4.38	3.81	0.045	1.12	1.93	2.34	0.48	28.38	9.8	12.43
	Nyamakanda w1	4.35	3.75	0.070	1.22	2.11	2.72	0.45	26.9	9.31	13.20
	Nyamakanda w2	4.58	3.8	0.024	1.73	2.98	2.62	0.66	33.59	7.24	19.69
	Rucanzongera w1	4.5	3.8	0.061	2.47	4.26	2.21	1.12	38.34	10	18.42
	Rucanzongera w2	4.48	3.74	0.093	2.45	4.22	2.01	1.22	34.56	6.15	12.97
Middle	Nyamakanda	4.76	4.13	0.074	1.41	2.43	1.23	1.15	25.35	8.39	12.88
	Satinsyi w1	4.9	4.14	0.081	1.46	2.52	2.40	0.61	22.18	9.43	13.11
	Satinsyi w2	4.97	4.21	0.048	1.57	2.71	2.31	0.68	30.56	9.03	13.06
	Rustiro w1	5.1	4.23	0.059	1.57	2.71	2.33	0.67	24.51	10.1	13.24
	Rustiro w2	4.81	4.07	0.066	1.54	2.66	2.37	0.65	28.17	9.72	12.80
	Nyamakanda w1	4.88	4.03	0.053	1.33	2.29	1.34	0.99	27.96	9.18	12.75
	Nyamakanda w2	4.93	3.99	0.036	1.33	2.29	1.87	0.71	16.97	8.61	12.16
	Rucanzongera w1	4.51	3.84	0.036	2.47	4.26	2.94	0.84	32.75	9.62	23.21
	Rucanzongera w2	4.49	3.84	0.046	2.45	4.22	3.01	0.81	29.45	8.67	22.92
Lower	Nyamakanda	4.52	3.8	0.039	1.28	2.2	1.98	0.65	18.24	8.73	13.04
	Satinsyi w1	4.4	3.84	0.040	1.46	2.52	2.57	0.57	30.28	9.11	12.58
	Satinsyi w2	4.83	3.92	0.035	1.62	2.8	2.27	0.71	23.94	9.24	13.27
	Rustiro w1	4.97	4.21	0.081	1.6	2.75	2.58	0.62	23.66	8.93	12.80
	Rustiro w2	5.1	4.23	0.048	1.52	2.61	2.34	0.65	27.39	10.09	12.75
	Nyamakanda w1	4.81	4.07	0.059	1.38	2.38	1.85	0.75	27.54	6.61	12.66
	Nyamakanda w2	4.88	4.03	0.066	1.33	2.29	2.03	0.66	26.34	6.71	12.21
	Rucanzongera w1	4.93	3.99	0.053	2.65	4.22	2.96	0.90	28.54	7.43	22.92
	Rucanzongera w2	4.51	3.84	0.030	2.42	4.22	3.32	0.73	25.31	5.98	25.04

Organic carbon and organic matter

The organic carbon (OC) in the upper and middle slopes were rated as medium ranging from1.38 to 2.47%, corresponding to 2.38 and 4.26% and 1.33 to 2.47% corresponding to 2,29 and 4.26 % OM respectively and there is no significant difference among physiographic positions (appendix 2). Rucanzongera catchment had high OC compared to other catchment, this is because, the agroforestry trees in this study area are older than the rest. The upper slope recorded high level of organic carbon when compared with the mid-slope and foot-slope but recorded no significant difference among the physiographic positions. The reason for variation may be caused by the adoption of different cultural practices (addition of crop biomass). This situation result in differences of the nature of organic matter present in the soil together with different rate of material transportation, deposition and mineralization at the various physiographic positions. The low values of OC were resulted from low pH (<5.5) which restricts microbial activities and retarded OM mineralization. Also the low values could be due to clearing of vegetation and erosion especially on mountainous land (Msanya *et al*., 2001).The relatively high amount of OC is probably induced by agroforestry system. Behera *et al*., (2016) and Sharma ,(2016)stated that, reduction of loss of organic matter and nutrients are enhanced through agroforestry systems.

Total nitrogen, available Phosphorus and C/N ratio

According to from EUROCONSULT (1989), Landon (1991), Sys (1993), Baize (1993), Msanya et al. (1996) and Kileo, (2000),The study sites showed a relatively high amount of available phosphorus ranging between 9.78 and 19.69 in the upper slope; 12.16 and 23.21ppm in the middle slope and 12.58 and 25.31 in the lower slope. Rucanzongera subwatershed seems to have high amount of available phosphorus than the rest. Also, available P is increasing downward the slope. The study sites also showed high level of total nitrogen except in the control where total nitrogen rated as low. The ANOVA table showed that there is a significant difference of TN, available. P and C/N ration among slopes.

High organic matter, nitrogen and phosphorus have been reported under tree growth compared to bare site (Misra,2011) reported an increase in organic matter, nitrogen and phosphorus of soil under the tree growth as compared to bare site (control).Various studies conducted in agroforestry systems support the view that trees helps in enrichment of nutrient pool by adding organic matter reducing losses and control soil erosion(Ndalama & Missanjo, 2015;Misra, 2018;Arévalo-Gardini *et al*., 2015).It is accepted that a large increase of nutrients stored in the trees and top soil compartments of tree based crop system, lead to greater efficiency in nutrient moisture status improvement due to canopy shade (Misra, 2018).The relatively low amount of available P may probably be due to continuous cultivation without replenishment of P or N from different P fertilizers.

The high value of nitrogen in the study area have been resulted from nitrogen fixing trees (agroforestry trees), enhanced availability of nutrient due to production and decomposition of tree biomass. Also the uptake and utilization of nutrients from deeper layers of soils by deep rooted trees have increased the nutrient content. Again these deep rooted trees in the system can contribute to improve soil physical conditions and higher soil microbial activities (Hazelton and Murphy, 2007). The C/N ratio in the study area is <25, this means that the decomposition of organic matter may proceed rapidly. and this value suggests good quality organic matter (Marx and Hart 1999).Organic matter with high C/N ratio (>20) affect nitrogen as it locks up nitrogen during decomposition and decreasing ammonium and nitrate to be taken by plant (Paudel *et al*., 2012)

Available nitrogen (N-NH_4 and N-NO_3)

The values of nitrate and ammonium are presented in (Table 4). According(Murphy and Hazalton, 2007), the upper , middle and lower slopes showed medium to high levels of nitrate ranging from 19.15 to 38.34 ;16.97 to 32.75 and 18.24 to 30.28 respectively. The level of nitrate and ammonium is affected by rainfall distribution, level of stored water at sowing and time sampling with depth at which sample was taken. The high values of nitrate (NO^-_3) in the study area may be due to fertilizer application containing nitrogen. Ammonium nitrogen concentration values are within the range(2-10ppm) of agricultural soil (Marx and Hart , 1999).

4.3. Soil quality index

The computation of soil quality index are shown in following formula (Bajracharya *et al*., 2006) and the rating was done using table 6.

SQI: $[(a*R_{STC}) + (b*R_{pH}) + (c+R_{OC}) +(d+R_{NPK})]$

Where,

SQI: Soil quality index

$R_{STC:}$ Ranking values for soil textural class

RpH: Ranking values for soil pH

R_{OC}: ranking values for soil organic carbon

R_{NPK}: Ranking values for Nitrogen, Potassium and Phosphorus

a: 0.2, b:0.1, c: 0.4, d:0.3

then for study area,

SQI: [(0.2*0.4) + (0.1*0.4) + (0.4+0.6) + (0.3+0.8)]

SQI: 0.08+0.04+1+1.1

SQI: 2.22

Table 6. Rating of SQI as described by NARC (1993)

	Ranking values				
Parameters	0.2	0.4	0.6	0.8	1
Soil textural class	S,C	CL,SL, SiC	Si, LS	L, SiLSL,	SiCL, SC
Soil pH	<4	4-4.9	5-5.9	6-6.4	6.5 -7.5
SOC	<0.5	0.6-1	1.1 -2	2.1 - 4	> 4
NPK	low	Moderate to low	moderate	Moderate to high	high
SQI	Very poor	Poor	Fair	Good	Best

According to table 6, the soil of the study area rated as best with SQI of 2.22. This mean that agroforestry system superior most in terms of maintaining high SQI

The higher values of SQI in the study area, show that this practice could increase the SQ, especial by enhancing soil labile carbon, microbial population, improving physical and chemical characteristic of soil (Tully et al., 2015 and Misra, 2018). This is the key factors in nutrient cycling and availability for plant growth.

4.3. Correlation between selected soil properties in the study area

The relationship among selected properties as shown in (table 6) has indicate that bulk density had a significant positive relationship (r=0.194) with clay. this means that the higher the clay content the higher the bulk density.

Available P had no significant difference with Ph and Organic carbon. Soil PHwater was not correlated with organic but was negatively correlated with pHkcl with a correlation coefficient of -0.272 indicating a decrease of pHkcl with increasing organic carbon.

Table 4. Correlation among some chemical characteristics of the studied soils

	PHwater	pHkcl	EC (dS/m)	% OC	% OM	% TN	C/N ratio	ppm N-NO3	ppm N-NH4	Av. P (ppm)
PHwater	1									
pHkcl	-0.07058	1								
EC (dS/m)	0.168828	0.358119	1							
% OC	.912**	-0.27293	-0.00935	1						
% TN	0.337367	-0.05816	-0.04426	.414*	.416*	1				
C/N ratio	-0.062	-0.27779	-0.13828	0.023251	0.023626	-.698**	1			
ppm N-NO3	.452*	-0.25496	0.051749	.530**	.528**	0.018926	0.118749	1		
ppm N-NH4	-0.01406	0.306958	0.161394	-0.08473	-0.08781	.486*	-.798**	-0.02726	1	
Av. P (ppm)	.477*	0.165984	0.098007	.420*	.424*	.731**	-.627**	-0.00635	0.288915	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

	% Sand	% Clay	% Silt	Textural classes	BD g/cm3	Particle density g,cm3	% Porosity	Aggregate stability
% Sand	1							
% Clay	-.836**	1						
% Silt	-.297	-.276	1					
Textural	-.500**	.566**	-.108	1				
classes	.008	.002	.593					
BD g/cm3	-.279	.194	.138	.297	1			
Particle density g,cm3	-.327	.360	-.047	.224	-.076	1		
% Porosity	.581**	-.652**	.116	-.413*	-.562**	-.160	1	
Aggregate stability	-.057	.068	-.017	.178	.049	-.194	-.014	1

CHAPTER IV.Conclusions and recommendations

5.1 Conclusions

The following conclusions can be drawn from the results of the study:

i. The study area showed good condition in term of bulk density and total porosity and aggregate stability.
ii. The textural classes indicate that the soil are more of sandy class.
iii. The soils of the study area showed relatively high level of nutrients (Nitrogen and phosphorus)
iv. In some sub watersheds where the agroforestry trees are still young, the distribution of the soil properties along the toposequence had indicated that most of the soil properties are more prominent at the foot-slope which results from erosional transportation and deposition.
v. In Rucanzongera sub watershed, the soil properties were not show any trend of change along a toposequence due to contribution of agroforestry system which have reduced erosion.

5.2. Recommendations

i. Due to coarse textured soil of the study area, conservation tillage practices should be used in order to reduce rate of soil loss, nutrient and erosion. Also, inorganic fertilizer should be used to argument the soil nutrient for enhanced crop production

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APPENDICES

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
PHwater	Between Groups	.331	2	.165	.380	.688
pHkcl	Between Groups	.306	2	.153	9.447	.001
EC (dS/m)	Between Groups	.000	2	.000	.200	.820
% OC	Between Groups	.000	2	.000	.001	.999
% OM	Between Groups	.001	2	.000	.000	1.000
% TN	Between Groups	.690	2	.345	1.067	.360
C/N ratio	Between Groups	1.391	2	.696	2.068	.148
ppm N-NO3	Between Groups	57.146	2	28.573	1.278	.297
ppm N-NH4	Between Groups	8.454	2	4.227	1.294	.293
Av. P (ppm)	Between Groups	67.412	2	33.706	3.116	.063

Appendix 1. Anova table for chemical properties

1.10. Appendix 2. Anova table for physical properties

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
% Sand	Between Groups	479.185	8	59.898	1.137	.387
% Clay	Between Groups	825.333	8	103.167	3.228	.019
% Silt	Between Groups	114.667	8	14.333	.697	.690
Textural classes	Between Groups	7.630	8	.954	1.981	.109
BD g/cm3	Between Groups	.255	8	.032	2.705	.038
Particle density g,cm3	Between Groups	.004	8	.000	2.281	.070
% Porosity	Between Groups	915.646	8	114.456	.872	.557
Aggregate stability	Between Groups	.273	8	.034	.960	.496

1.11. Appendix 3. Guide to general rating of some chemical and physical soil properties

The general rating has been compiled from EUROCONSULT (1989), Landon (1991), Sys (1993), Baize (1993), Msanya et al. (1996) and Kileo, (2000).

1. **Organic matter and total nitrogen**

	Very low	**Low**	**Medium**	**High**	**Very high**
Organic matter %	< 1.0	1.0-2.0	2.1-4.2	4.3-6.0	> 6.0
Organic carbon %	< 0.6	0.60-1.25	1.26-2.50	2.51-3.50	>3.5
Total nitrogen %	< 0.10	0.10-0.20	0.21-0.50	> 0.50	

C/N ratios give an indication of the quality of organic matter:

C/N 8-13: good quality

C/N 14-20: Moderate quality

C/N > 20: Poor quality.

2. Soil reaction

Extremely acid	**pH<4.5**	**Neutral**	**pH 6.6 to 7.3**
Very strongly acid	pH 4.5 to 5.0	mildly alkaline	pH 7.4 to 7.8
Strongly acid	pH 5.1 to 5.5	moderate alkaline	pH 7.9 to 8.4
Medium acid	pH 5.6 to 6.0	strongly alkaline	pH 8.5 to 9.0
Slightly acid	pH 6.1 to 6.5	very strongly alkaline	pH > 9.0

3. **Available phosphorus and cation exchange capacity**

mg/kg	**Very low**	**Low**	**Medium**	**High**	**Very high**
Avail. P (Bray-Kurtz 1		< 7	7-20	> 20	
Avail. P (Olsen		< 5	5-10	> 10	
(CEC) cmol(+)/kg	< 6.0	6.0-12.0	12.1- 25.0	25.0- 40.0	> 40.0

NB. Available phosphorus is determined by the Bray-Kurtz 1 method if the pH H2O of the soil is less than 7.0. In soils with a pH H2O of more than 7.0 the Olsen method is used.

CEC is determined using 1 M ammonium acetate in soils with pH less than 7.5. In soils with pH greater than 7.5 CEC is determined using 1 M sodium acetate.

5. Electrical conductivity (ECe)

ECe	**< 1.7 dS/m**	**no yield reduction**
ECe	1.7 - 2.5 dS/m	up to 10% yield reduction
ECe	2.5 - 3.8 dS/m	up to 25% yield reduction
ECe	3.8 - 5.9 dS/m	up to 50% yield reduction
ECe	5.9 - 10 dS/ m	up to 100% yield reduction