

**ASSESSING THE EFFECTIVENESS OF SUPPLEMENTARY IRRIGATION AND SOIL  
CONSERVATION TECHNIQUES ON MAIZE IN CYILI SUB-CATCHMENT,  
RWANDA**

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**A56/81993/2015**

**A thesis submitted in partial fulfilment of the requirements for award of  
Master of Science in Land and Water Management in the Department of Land Resource  
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**DECLARATION**

I, **Dieudonne Uwizeyimana** declare that this thesis is my original work and has not been previously submitted for the award of a degree in any other University or Institution of higher learning.

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## **DEDICATION**

This work is dedicated to the Almighty Lord and to my late Aunt Sr. Veronique Ukwabizi, who during her life time established a foundation for my education. I also dedicated this work to my mother Gertrude Niyirora for her love and support.

## ACKNOWLEDGEMENTS

This work was supported by the United States Agency International Development (USAID), as part of the Feed the Future initiative, under the CGIAR Fund, award number BFS-G-11-00002. And the predecessor funds the Food Security and Crisis Mitigation II grant, award number EEM-G-00-04-00013. My special thanks for the financial support and nice cooperation.

I would like to thank my University Supervisors Dr. Stephen M. Mureithi, Dr. George. N. Karuku, and Prof. Geoffrey Kironchi, for the help they provided and the guidance they kindly gave me during this study. Your invaluable contribution to this research is highly appreciated. I would like also to thank Dr. Martin Simon Mvuyekure, Head of wheat research program at Rwanda Agriculture Board (RAB) for the constructive discussions and useful advice accorded to me. Thank you for all the opportunities you gave me and the scientific input, constructive comments. I would like to acknowledge the technical support; I received from Mr.Theogene Niyibigira, Mr. Aimable Gahigi, and Mr. Eustacher Nkekahizi staff members at the Rwanda Agriculture Board. Many thanks are due to Mr. JMV Rusiribana Head of Commodity Chain Department at SPIU/LWH-RSSP MINAGRI for encouragement and advice to study; your kindness will always be cherished. I am also thankful for the support received from colleagues, Peter.J Munyantarama, Munderi Salathiel, and his family, Lotome Chammah during this research project.

I would like to thank all the MSc students and staff at University of Nairobi for their friendship and nice discussions. Many thanks, to all the farmers in Cyili sub-catchment for their role of allowing me conduct the research in their farms. Last but not least, I would like to thank my mother and aunties for raising me up and teaching me to be patient, my sisters, brother and cousins for their deep love, good care and prayers for me. God bless you all

## TABLE OF CONTENTS

<b>DECLARATION.....</b>	<b>i</b>
<b>DEDICATION.....</b>	<b>ii</b>
<b>ACKNOWLEDGEMENTS .....</b>	<b>iii</b>
<b>TABLE OF CONTENTS .....</b>	<b>iv</b>
<b>LIST OF FIGURES .....</b>	<b>vii</b>
<b>SUMMARY .....</b>	<b>ix</b>
<b>CHAPTER ONE .....</b>	<b>1</b>
<b>GENERAL INTRODUCTION.....</b>	<b>1</b>
1.1 Background information .....	1
1.2 Statement of the Problem.....	2
1.3. Justification of the Study .....	3
1.4. Objectives .....	4
1.4.1 Broad objectives .....	4
1.4.2 Research Hypotheses.....	5
1.5. Description of the study area .....	5
1.6. Scope of the study and structure of the thesis.....	7
<b>CHAPTER TWO .....</b>	<b>9</b>
<b>LITERATURE REVIEW .....</b>	<b>9</b>
2.1 Surface runoff .....	9
2.2 Rainwater Harvesting.....	11
2.3 Supplementary irrigation .....	11
2.4 Drum irrigation system .....	12
2.5. Crop water requirements.....	13
2.6. Irrigation water requirement .....	13
2.7 Irrigation interval .....	13
2.8 Effective Rainfall .....	13

<b>CHAPTER THREE .....</b>	<b>14</b>
Available soil water requirement for maize production in Cyili sub-catchment during the short rain seasons. ....	14
<b>CHAPTER FOUR.....</b>	<b>30</b>
Surface runoff volumes generated from the Cyili sub-catchment of rwanda during the short rain seasons .....	30
<b>CHAPTER FIVE .....</b>	<b>49</b>
The effect of ridging, mulching and supplementary irrigation on maize yield in Cyili sub-catchment during the short rain seasons .....	49
<b>CHAPTER SIX: .....</b>	<b>67</b>
General conclusion and recommendations .....	67
<b>REFERENCES.....</b>	<b>71</b>
<b>APPENDICES.....</b>	<b>88</b>

## LIST OF TABLES

<b>Table 3.1</b> Average seasonal climatic data in Cyili sub-catchments from 1971 to 2016 .....	22
<b>Table 3.2</b> Soil moisture content (%) variation along the Cyili sub-catchment .....	23
<b>Table 3.3</b> Crop water requirement for maize during short rain season (2016-2017) at Cyili sub-catchment .....	26
<b>Table 3.4</b> Irrigation water requirement and irrigation scheduling .....	28
<b>Table 3.5</b> Irrigation scheduling development.....	29
<b>Table 4.1</b> Hydrological soil groups and soil texture of Cyili sub-catchment.....	43
<b>Table 4.2</b> Weighted Curve Number values and runoff volumes of Cyili sub-catchment .....	45
<b>Table 4.3</b> Seasonal rainfall water balance of Cyili sub-catchment .....	46
<b>Table 5.1</b> Mean performance of maize growth parameters under different water conservation methods... ..	59
<b>Table 5.2</b> Mean performance of maize yield parameters under soil water conservation methods .....	61
<b>Table 5.3</b> Mean performance of grain yield data under various water conservation methods ....	62
<b>Table 5.4</b> Pearson's correlation coefficient matrix between maize grain yield and yield components .....	65

## LIST OF FIGURES

<b>Figure 1.1</b> Map of Cyili sub-catchment location .....	6
<b>Figure 2.1</b> Drum drip irrigation system .....	12
<b>Figure 3.1</b> Map of Cyili sub-catchment location .....	17
<b>Figure 3.2</b> Surface soil moisture sampling points in the study area .....	18
<b>Figure 3.3</b> Soil moisture variation in Cyili sub-catchment during short rainy season 2016-2017 .....	25
<b>Figure 4.1</b> Map of Cyili sub-catchment location .....	33
<b>Figure 4.2</b> Soil classification map of Cyili sub-catchment .....	34
<b>Figure 4.3</b> A flowchart used for modeling potential runoff and water requirement in Cyili sub-catchment .....	35
<b>Figure 4.4</b> Soil texture sampling points in the study area .....	38
<b>Figure 4.5</b> Topography elevation of Cyili sub-catchment .....	40
<b>Figure 4.6</b> Cyili sub-catchment Triangulated Irregular Network .....	41
<b>Figure 4.7</b> Cyili sub-catchment rainfall distribution in short rains seasons .....	42
<b>Figure 4.8</b> Land use in Cyili sub-catchment .....	44



## ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
CABI	Centre for Agriculture and Bioscience International
CIAT	International Center for Tropical Agriculture
CN	Curve Number
CRD	Completely Randomized Design
FAO	Food Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization Statistical Database
IFAD	International Fund for Agriculture Development
LSD	Least Significant Difference
LWH	Land Water Harvesting
m a.s.l	meters above sea level
MINAGRI	Ministry of Agriculture and Animal Resources (Rwanda)
NISR	National Institute of Statistics of Rwanda
NRCS	Natural Resource Conservation Service
PVC	Polyvinyl Chloride
REMA	Rwanda Environmental Management Authority
RIWSP	Rwanda Integrated Water Security Programme
RSSP	Rural Sector Support Project
RWH	Rain Water Harvesting
SCS	Soil Conservation Service
SI	Supplementary Irrigation
SPIU	Single Project Implementation Unit
UNESCO	United Nations Educational, Scientific and Cultural Organization
USAID	United States Agency for International Development
USDA	United State Department of Agriculture
WWAP	World Water Assessment Program

## SUMMARY

Limited natural water resource and unpredictable rainfall are challenges to agricultural production in East Africa. Modeling surface runoff in agricultural catchment is essential for water management currently and in the future. A study was conducted in Cyili sub-catchment, Southern Province of Rwanda during the short rainy season from 15<sup>th</sup> September, 2016 to 20<sup>th</sup> February 2017 with the aim to assess the potential of supplementary irrigation using surface runoff generated from the Cyili catchment. The study assessed soil moisture variation and supplementary irrigation water requirement for maize during short rainy season by quantifying the runoff volume generated in Cyili sub-catchment. The soil water conservation methods assessed included; mulching, contour ridges and supplementary irrigation using harvested surface runoff.

A multi-method experimental and modeling activity was used to achieve the research objectives. The experimental design consisted of three treatments of water conservation methods and rainfed as a control. These were replicated three times in completely randomized design (CRD). Data obtained were subjected to analysis of variance using Genstat 14<sup>th</sup> edition. Treatment mean differences were evaluated using least significant difference (LSD) at 5% level of significance. Relationships between grain yield and yield components under water conservation methods were analysed using Minitab software version 17. Twelves soil samples were taken at a depth of 0-30cm and 30-60cm depth in the top, middle and bottom of the catchment. Soil moisture was determined by Gravimetric method. Supplementary irrigation water requirement was estimated using CROPWAT model version 8. Surface runoff volume was estimated using Soil Conservation Service-Curve Number method and ArcGIS version 10.1

Results revealed that soil moisture variation in the subsoil was significantly ( $p \leq 0.05$ ) higher than the topsoil  $4.81 \pm 4.08\%$  and  $3.54 \pm 1.77\%$  (mean $\pm$ SD), respectively. Results from the kriging method revealed that the soil moisture distribution for both soil layers were low in the lower and high in the upper part of the sub-catchment. Supplementary irrigation water requirement in the cropping season A (October to January) was 127mm ( $1,270\text{m}^3/\text{ha}/\text{season}$ ) with an application efficiency of 70% and translating to the entire catchment area (430ha) requirement of  $546,100\text{m}^3/\text{season}$ . The seasonal surface runoff volume was 300.85mm ( $3008.5\text{m}^3/\text{ha}/\text{season}$ ). The maize grain yield and yield components such as plant height, cob diameter and length, number of leaves per plant, 100grains weight, yield per plant were significantly ( $P \leq 0.001$ ) affected by water conservation methods except the germination rate was not significant ( $p > 0.05$ ). Supplementary irrigation treatment significantly increased maize yield production at 11,982kg/ha compare to other water conservation methods (mulching, ridge and rainfed). This was followed by mulching significantly increased to 8,089 kg/ha compared to the rainfed treatment (control). Ridges produced 5, 937 kg/ha, and was not significant compared to the rainfed treatment with no additional treatment yielded 4,755 kg/ha of maize. Based on Pearson's correlation coefficients, grain yield and yield components were positive and statistically significant ( $p \leq 0.001$ ) under various water conservation methods. Based on these results, mulching and supplementary irrigation using harvested runoff can be regarded the potential option for increasing maize yields to stabilize food production under rainfall deficit agro-ecological conditions in Rwanda and other parts of sub-sahara Africa.

**Keys words:** Cyili sub-catchment, Drought, runoff, Rwanda, Soil moisture, Supplementary irrigation

# CHAPTER ONE

## GENERAL INTRODUCTION

### 1.1 Background information

The world farmers' generally depend on rainfed farming (82%) (Descheemaeker *et al.*, 2013; Sharma, 2011). In sub-Saharan Africa more than 93% of food and cash crop generated from rainfed agriculture (Sharma, 2011), only 5% cultivated land in Africa was irrigated and 4% in Rwanda (NISR, 2017; WWAP, 2015). Nevertheless water scarcity, uneven rainfall distribution temporal and spatial, soil erosion (wind and water), flooding, drought, population growth are the main challenges for rainfed farming not only in sub-Saharan Africa but in the Worldwide (Gebrehiwot and Gebrewahid, 2016). Therefore, adoption of soil and water conservation technologies, supplementary irrigation through rainwater harvesting, deficit irrigation method and improved hybrid seeds tolerant to drought are the best way to alleviate the food security in sub-Saharan Africa.

Previous studies (Pandey *et al.*, 2013; Chander *et al.*, 2011; Pathak *et al.*, 2009) findings show that runoff improve agricultural production especially in the region with low rainfall (semi-arid), supplemental irrigation is required to protect crops during the period of dry spell. The Centre for Agriculture and Bioscience International (CABI) (Oweis and Hachum, 2009) reported that yields of rainfed agricultural may possibly double in Asia and quadruple in Africa if farmers' fields develop and adopt the soil and water conservation methods. Rwanda needs to improve agricultural production to mitigate food insecurity and to decrease the quantity of the imported foods. Agriculture sector contribute 33% of Rwanda's economy (NISR, 2016) accounts the third

place of gross domestic product of country. Above 80% of the country inhabitants are the agriculturalists and 90% of the food produced in Rwanda is consumed by Rwandese people (NISR, 2016 and Nyasimi *et al.*, 2016).

In Rwanda, agricultural water development is needed especially in Mayaga agro-ecological zone, the southeast and eastern part of the country (Warnen *et al.*, 2015). The 589,713 ha of agricultural land in Rwanda has irrigation potential to increase agricultural production, through use of the available natural water resource of the country like the rivers, lakes, groundwater, and runoff generation from precipitation (Malesu *et al.*, 2010). However, these available water resources are not well managed. According to MINIRENA (2015) report that about 30-40% of its available water lost as inefficient supply systems. The country uses only 2% of its available water resources. The situation is critical in the hillside of Rwanda, especially in the eastern and southeast part of the country where precipitation is limited (Haggag *et al.*, 2016). There is therefore a need to adapter supplementary irrigation using rainwater harvesting and water conservation method in Cyili sub-catchment where farmers' fields are left fallow because of inadequate distribution rainfall. The purpose of this research is to contribute towards improving agricultural production through evaluating efficiency of soil conservation practices and potential of supplemental irrigation in Cyili-sub-catchment.

## **1.2 Statement of the Problem**

Rwanda has a total surface area of 26,338 km<sup>2</sup> and most inhabited in Africa (Musabanganji *et al.*, 2016), with inhabitants density of 467 people/square km (NISR, 2016). The heavy demographic pressures generate division of land into very small parcels; overexploitation and topsoil productivity decreases (Ansoms *et al.*, 2008). Small parcels agricultural land of less than

one hectare account for 72.4% and 40-50% of agricultural land are on hills with an average slope of 16-40% (World Bank and CIAT; 2015 ).

Rwanda agriculture sector is vulnerable to climate change because rainfall patterns are more irregular, especially in a shorter rainy season (Ndayisaba *et al.*, 2016; Warnen *et al.*, 2015; Rwanyiziri and Rugema, 2013). Every year the prolonged droughts and insufficient rainfall have increased resulting in crop lower yield in Rwanda (Kabirigi *et al.*, 2015; Warnen *et al.*, 2015). Cyili sub-catchment is one of the areas where, farmers are facing the problem of uneven rainfall distribution both in temporal and spatial during the short rainy season (September to January). In many instances farmers have lost the whole crop or experienced drastic reduction in crop yield during the dry spells due to erratic rainfall. In order to ensure sustainable development in agriculture, especially food security, water conservation and rainwater harvesting for supplementary irrigation technologies are required to enhance production.

### **1.3. Justification of the Study**

Many researchers' (Dile, *et al.*, 2013; Pandey *et al.*, 2013; Rockström *et al.*, 2010) have stated that supplementary irrigation through rainwater harvesting increases crop production. A recent study by Jägermeyr *et al.*, 2016 found that 200 mm per annum volume of rainwater storage can increase crop productivity in semi-arid regions. The Cyili sub-catchment rainfed agriculture is a common practice. Consequently, there is irregular rainfall distribution to keep up crop growing during short rains season (A). The problem of dry spells take place in the middle of September to December for during short rainy season. However, a lot of rainwater is lost as run-off during that period. The present study shows the opportunity of using surface runoff water for supplementary irrigation and soil moisture content management through various water conservation methods

(mulching, contour ridge) was not known to the farmers of Cyili sub-catchment. This research also intends to answer the following questions: is bench terraces an efficient soil moisture conservation technique? How much of the crop water requirements are not met by rainfall and when is it appropriate to supplement? What are the best agricultural practices in low rainfall areas? Results obtained from this research will aid policy makers, the world community, individual farmers and researchers to implement this technology.

#### **1.4. Objectives**

##### **1.4.1. Broad objectives**

The broad objective was to assess the effectiveness of supplementary irrigation and soil conservation techniques on maize in Cyili sub-catchment

##### **Specific objectives**

The specific objectives of the study were:

1. To assess the available soil water requirement for maize production in Cyili sub-catchment during short rainy cropping season.
2. To quantify the amount of runoff generated from Cyili sub-catchment during the short rainy season.
3. To determine the effects of mulching, ridging, supplementary irrigation on maize yield in Cyili sub-catchment during the short rains season.

## **1.4.2 Research Hypotheses**

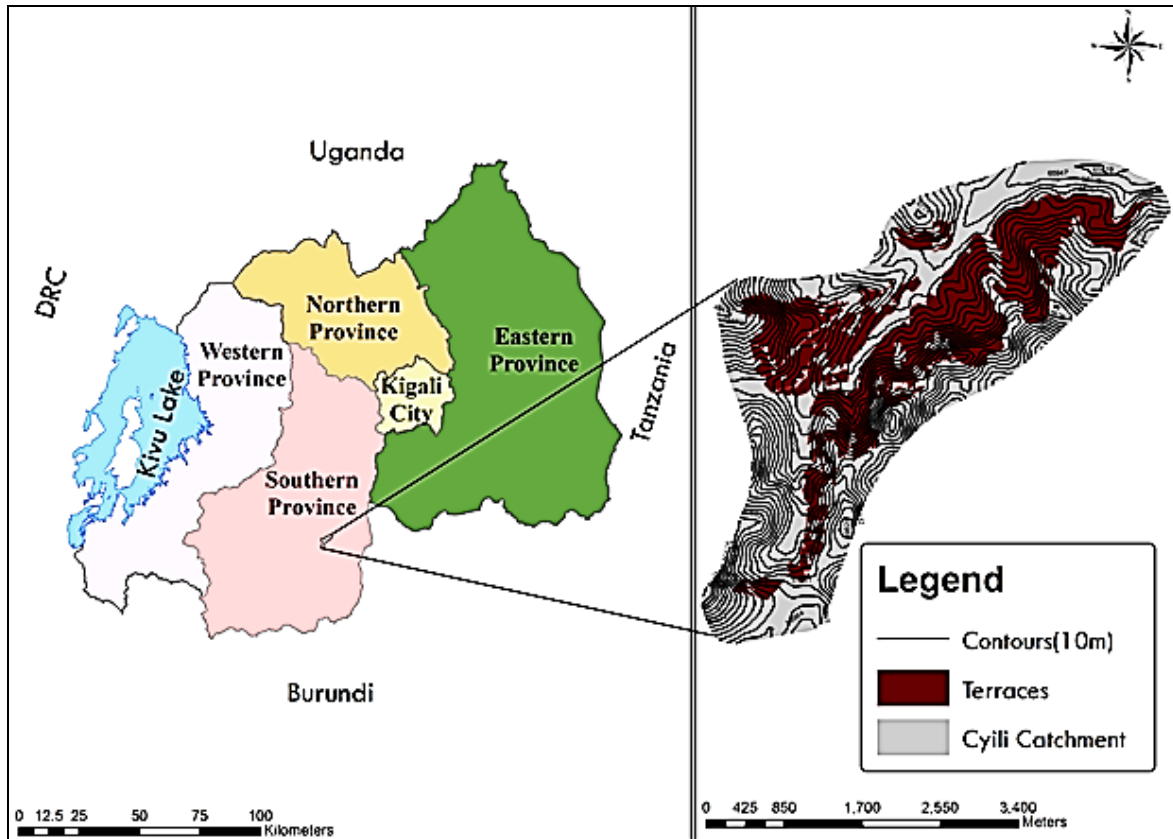
1. Cyili sub-catchment has sufficient soil moisture to sustain a maize crop optimal yield.
2. Cyili sub-catchment generates adequate runoff water to supplement maize crop water requirement on terraced land.
3. There is significant difference between the different agricultural practices on maize yield production.

## **1.5. Description of the study area**

### **1.5.1. Location and geo-physical characteristics of Cyili sub-catchment**

This study conducted in Rwanda, a landlocked country of 26,338km<sup>2</sup> in area (Verdoodt and Ranst, 2003). It is located in between latitudes of 1°04' and 2°51' South and longitudes 28°45' and 31°15' East (Munyaneza, 2014; Kayiranga, 2006). The topography is hilly and mountainous with the altitude varying from 950 to 4,507 m above sea level (Munyaneza, 2014). The study area (Cyili sub-catchment) is located in Huye and Gisagara districts of southern province of Rwanda, 149 Km from Kigali city (MINAGRI, 2010). The elevations vary between 1410 to 1795 m above sea level. Most of the cultivated land is on steep slopes which are conserved with bench terrace Figure 1.1.





**Figure 1 1: Map of Cyili sub-catchment location**

### **1.5.2. Climate**

The climate of the study area is classified as sub-humid and fall under Mayaga agro-ecological zone IX of Rwanda (see Appendix 1 map of Rwanda agro-ecological zone) with extreme spatial and temporal rainfall distribution (Verdoodt and Ranst, 2003). The Cyili sub-catchment receives annual rainfall of 1,141.1 mm at Rubona station. Rainfall is bimodal with long rains in March to May and the short in mid-September to mid-December. Annual temperature ranges from 14.2<sup>0</sup>C minimum to 24.8<sup>0</sup>C maximum (MINAGRI, 2010).

### **1.5.3. Soils and water resources**

The Cyili sub-catchment has a wide range of soil types and climate similar to the central plateau (middle altitude) of the country. The dominant soil types are Luvisols, Alisols and Cambisols

(FAO/UNESCO, 2003). The water of Cyili sub-catchment comes from Nyarwambo, Birori, Rwasanzu, Muyanga and Gahishiyi rivers. It is also considered as a sub-catchment of Akagera catchment (MINAGRI, 2010).

#### **1.5.4. Land use and vegetation**

Agriculture is the main activity in the study area. The dominate crops on the hillside of sub-catchment are maize, beans, sorghum cassava, soybean, groundnuts, coffee and fruit trees such as avocado and oranges. At the valley areas of sub-catchment, rice, tomatoes, cabbages, onions are dominant (MINAGRI, 2010; Kayiranga, 2006).

#### **1.6. Scope of the study and structure of the thesis**

This thesis is divided into three parts. The first part provides an introduction into soil and water conservation and supplementary irrigation through runoff water harvesting as material for improving agricultural production and it also defines the scope of the study which includes objectives and research hypothesis as well as the statement of the problem. It also describes the current situation of the study area in chapter 1. The second part reviews the best agricultural practices that can generate higher yield in chapter 2 to 5.

Chapter 2 and 3 reviews the background of the study area. The main points are to determine soil available water requirement for maize under drought prone agro-ecological zone. The application of CROPWAT version 8 and ArcGIS version10.01 in Cyili sub-catchment are detailed in this chapter. Chapter 4 assesses the runoff generated in Cyili sub-catchment. The land curve number

method is used in this chapter and the land use, slope map is digitalized to estimate runoff volume. The effective rainfall, probability of occurrence, water loss is determined in this chapter.

Chapter 5 evaluates the best agricultural practices (ridging, mulching and supplemental irrigation) that can generate higher yield and benefits. The correlation coefficient of yield and yield components (height, number of leave and cob, cob diameter, number of grain per plant, yield per hectare) are determined in this chapter. The third part contained in chapter 6 provides a general discussion and conclusion from all the chapters, and provides fruitful awareness for future research and recommendations.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Surface runoff

Surface runoff is the surplus water on land surface produced by rainfall or other source of water which is not evaporated or stored in the soil surface eventually flow over the Earth's surface (Li et al, 2015) and it's happens after soil saturation where, soil infiltration rate is low to the rate of rainfall on surface. It is one of the major constituents of the hydrological cycle (Muthu *et al.*, 2015). Runoff water sometimes is helpfully in agriculture, in event of dry spells where use it as supplementary irrigation and can improving soil moisture content and ground water discharge (Desta, 2004).

##### 2.1.1 The factors affect runoff from agricultural land

Runoff generated in agriculture land influenced by land topography, shape of watershed and rainfall intensity (Vaezi et al, 2010.; Bao and Laituri, 2013). Soil physical properties is critical factor to determine the volume of runoff generation (Gilley et al, 2002), a study by Fang et al, (2015) find erratic rainfall pattern influence runoff generation over time, soil properties also are important particularly, soil holding capacity; soil infiltration; soil water contents and soil structure. Humid areas soil moisture variation is distributed to the difference depth of soil profile (Vaezi et al., 2010),complementary in semi-arid, soil properties and rainfall characteristics are primarily responsible for controlling soil moisture variation in soil profile (Martinez et al, 1998).

### **2.1.2 Effect of the catchment size for generating runoff**

Catchment area is an area of land which is bounded by natural features such as hills or mountains from which water flows to a low point. The low point can be a dam, stream or the mouth of a river where the water enters a inlet the lake or sea (Yang *et al.*, 2011). Sub-catchment is a subdivision of catchment and is used to describe an area that drains into a small rivers or streams (Nkpeebo *et al.*, 2016). A basin is an area of land with more than two catchments that drains all rainfall volume of flow to a large river of country or a continent (Ulzetueva *et al.*, 2017).

Runoff generated in catchment influenced by land topography, the shape of the watershed and rainfall intensity (Bao and Laituri, 2013; Vaezi *et al.*, 2010). A study by (McGlynn *et al.*, 2004) size of catchment effect for runoff generation at Riparian, new Zealand, observed they are two factors influence runoff generation in catchment: the first factor, large catchment areas having temporary places of storage runoff in surface area depressions. A small catchment generates low yield of runoff volume due to the small areas. Soil physical properties is critical factor in determining the runoff volume (Gilley *et al.*, 2002).

### **2.1.3 Soil Conservation Service Runoff Curve Number Method (SCS-CN)**

The SCS-CN is a method developed by Agriculture Department of the United State (USDA) to predict and to estimate direct runoff volume or excess rainfall generated in the land surface (USDA, 1986). The SCS has developed this method by combining into a single parameter of the effects of soils, watershed characteristics, and land use. Runoff curve number (CN) parameter presents complex cover vegetation, and the hydrologic soil group of catchment. Data required to determine runoff curve number for catchment, are soil type parameters data, cover description data and climatic data (NRCS, 2004).

#### **2.1.4 Soil Hydrologic Groups (HSG)**

Hydrologic soil groups are the soils having the same potential of runoff under the same rainstorm and cover environments (conditions), considered to determine the volume of runoff from rainfall. According to NRCS (2004), soil is categorized in four groups of soil hydrologic soils includes, A, B, C and D where, A: are sandy soils characterised great infiltration rates with very low potential runoff volume, B: loamy or silt loamy soils with moderate potential runoff and infiltration rates, C: sand clay loam soils with runoff potential and slow infiltration rates, and D: clay loamy soils which is characterised high runoff potential and very slow infiltration rates. Soil groups are therefore important factors to consider when determining runoff since some permit rain water to penetrate faster than others.

#### **2.2 Rainwater Harvesting**

Rainwater harvesting is the collection and storage of rainwater into reservoir designed for productive use (Njuguna and Solinas, 2014). It is a good practice for the hydroelectric power plants and in agriculture for increasing crop productivity and water (Muthu and Santhi, 2015; T. Oweis & Hachum, 2009). Ngigia et al. (2005) and Julius et al. (2013) reported that the farm pond improved agricultural productivity and deliver solution of water deficit in semi-arid region in sub-Saharan Africa.

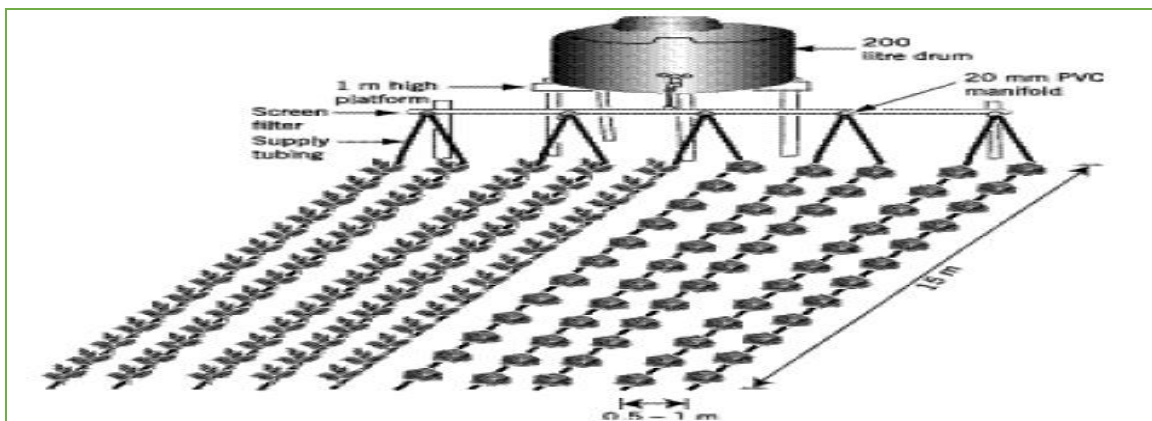
#### **2.3 Supplementary irrigation**

Supplementary irrigation is a technique applied irregularly based on the available rainfall adds volume of water to the plants in the critical time to improve and secure yields (Oweis *et al.*, 1999), once rainfall is limited to support plant growth supplementary irrigation is one of solution to raise soil water content and to protect crops water stress in dry spells period. A study by Oweis and Hachum (2012) find three conditions plants required to add water: once rainfall is

low; when water applied provide soil moisture stress and if plants or crops will not able to produce maximum yield no irrigation. Previous studies in different parts of the world reported that supplementary irrigation has increased crop yields, Doto et al.(2015) in Burkina Fuso country, Li & Gong (2002) Northwest of China and Karasu et al.(2015) in Bursa Marmara region, Turkey

## 2.4 Drum irrigation system

Drum irrigation system defined as the irrigation system use a small tank or drum to irrigates the small area. The volume of drum varies between 100 to 200 liters. The main components of drum system are a drum or small tank (reservoir) manifold with PVC of 20 mm which is connected to the screen filter, lateral line with the length of 15m up to 30 m and made in PVC of 2.5cm diameter. The drum of water is raised at least 1m above soil surface to provide adequate pressure head in the drip lines for uniform distribution of water (Camara *et al.*, 2010).



**Figure 2 1: Drum drip irrigation system**

## **2.5. Crop water requirements**

Crop water requirements is the amount of water that crop requires during growth, from the sowing to harvesting (Frenken and Gillet, 2012). Crops have different water requirement depending on different factors such as crop variety, soil type, climate and method of cultivation water required for growing; but this quantity of water varies depending on different factors such as crop variety, soil type, climate and method of cultivation (Al-Kaisi and Broner, 2009).

## **2.6. Irrigation water requirement**

Irrigation water requirement is defined as the part of water requirement of plant growth that should be added through irrigation to stabilize yield production. Irrigation water is the difference between crop evapotranspiration and effective rainfall plus any soil water contents or ground water contribution in the soil profile (USDA-SCS, 1967).

## **2.7 Irrigation interval**

Irrigation interval is the period of time between successive irrigations in the same portion of the field. However, the shortest interval of irrigation is desirable for obtaining potential yield of the crop (Phocaides, 2007).

## **2.8 Effective Rainfall**

Effective rainfall is the amount of rainfall that is available in the root zone of the crops, allowing the crop to develop and maintain its growth (Cahoon *et al.*, 1992; USDA-SCS, 1967).



## CHAPTER THREE

### AVAILABLE SOIL WATER REQUIREMENT FOR MAIZE PRODUCTION IN CYILI SUB-CATCHMENT DURING THE SHORT RAIN SEASONS.

#### Abstract

Understanding soil moisture variation is pertinent for proper implementation of suitable agricultural practices. The purpose of this study was to determine soil moisture variation and supplemental irrigation water requirement for maize in Cyili sub-catchment. Gravimetric method and CROPWAT version 8 model were used to determine soil moisture and supplementary irrigation water requirement, respectively. Maize variety 'PAN53' was the test crop. Twelve soil profiles were selected randomly along the landscape of sub-catchment, at the top, middle and bottom. Undisturbed soil samples were taken at 0–30 cm and 30–60 depth from October 2016 to January 2017. The results indicated that soil moisture variation were significantly less at the topsoil  $3.54 \pm 1.77\%$  than in the subsoil  $4.81 \pm 4.08\%$ , respectively at ( $p \leq 0.05$ ). Results from the kriging method revealed that the soil moisture distribution for both soil layers were low in the lower and high in the upper part of the sub-catchment. Supplementary irrigation water requirement for maize in the cropping season of October 2016 to January 2017 was 127mm ( $1,270\text{m}^3/\text{ha}/\text{season}$ ) with an application efficiency of 70%. The  $546,100\text{m}^3/\text{season}$  are total volume water requirement at the entire whole catchment areas (430ha). The month of December had the highest irrigation water requirement 12.6mm/ha while no supplementary irrigation was required in October and November during the study period. The net irrigation water requirement for the entire growing period (October 2016 to January 2017) was 88.9mm/season ( $889\text{m}^3/\text{ha}/\text{season}$ ) and irrigation interval recommended was 10 days at development stage.

**Keys word:** Cyili sub-catchment, Maize, Short-rainy season, Soil moisture, Supplementary irrigation,

### **3.1. Introduction**

Soil moisture content is the amount of water stored into the soil at a given time (Rogers et al., 2014). It influence earth surface processes, such as runoff, erosion, as well as transport of solutes and water (Rong *et al.*, 2017; Brocca *et al.*, 2010). The interaction between soil moisture, plants, and atmosphere affect crop growth as it regulates and dissolves the nutrient necessary for crop growth. The optimum soil moisture content helps the crop to absorb soil nutrients (Rong *et al.*, 2017; Baudena *et al.*, 2008). The knowledge of the available water in the soil is important in irrigated agriculture for determining when irrigation should be applied including the water-holding capacity of the soil (Morison *et al.*, 2008). It is also important factor required for increasing water-use efficiency by plants is how much water is available in the soil at important plant stages in seasons (Evans *et al.*, 2008).

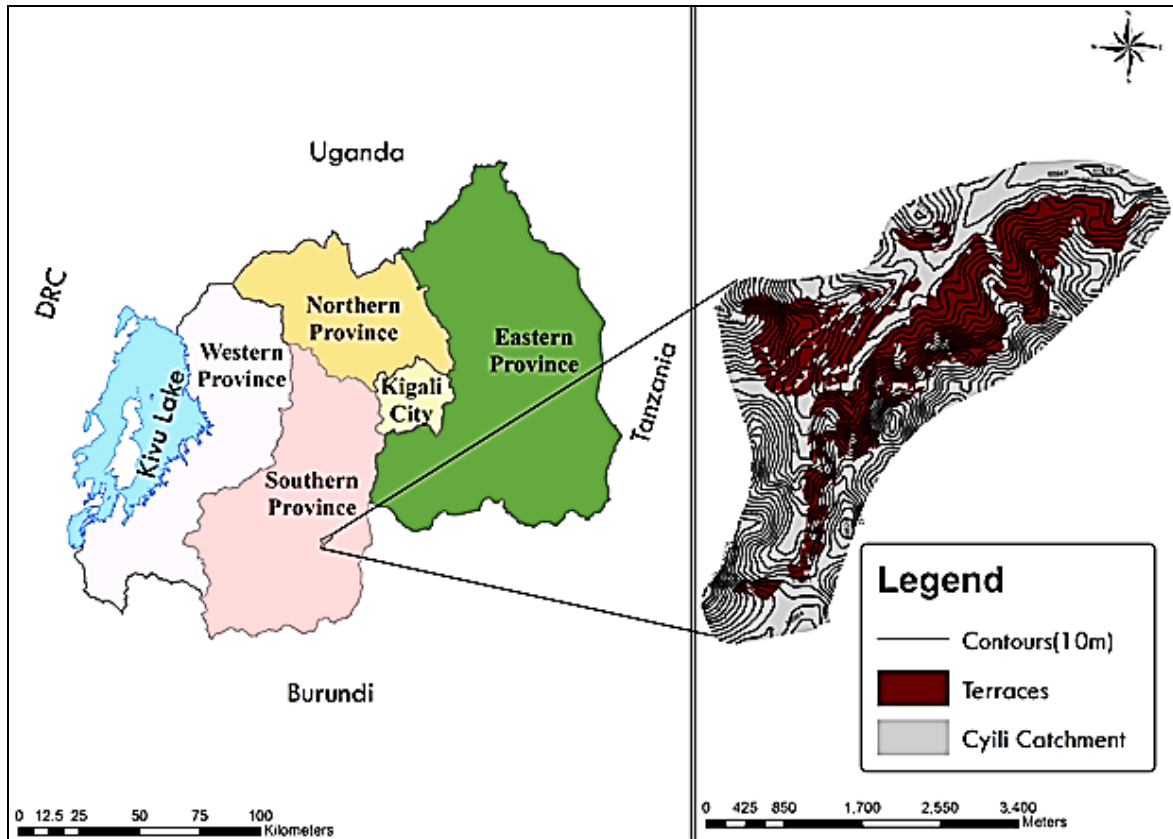
Variations and reduction of annual rainfall in most regions of the sub-Sahara Africa have led to frequent droughts (Serdeczny *et al.*, 2016). According to Rwanda Environmental Management Agency (REMA, 2006), the country has experienced negative effects on water availability for agriculture due to the climate change in the last 30 years. The quantity of rainfall in the country has declined while at the same time temperatures have increased (Haggag *et al.*, 2016), putting pressure on water supplies.

Cyili sub-catchment fall under drought agro-ecological zone (Mayaga, IX) based on climate and soil types characteristics (Verdoodt and Ranst, 2006). The sub-catchment is characterized by erodic rainfall and soils with low water retention capacity that are dominated by Luvisols and Cambisols (FAO/UNESCO, 2003). These properties affect soil moisture and consequently plant growth and production which are the basic agricultural challenge in Cyili sub-catchment. Therefore, rain-water-harvesting and supplemental irrigation is necessary to mitigate dry spells during short rainy cropping season. The knowledge of moisture content is very important to farmers for irrigation development and assessing available water for plant growth. The objective of this study was to determine soil moisture variation and supplemental irrigation water requirement for maize crop in Cyili sub-catchment during short rainy cropping season.

## **3.2. Material and Methods**

### **3.2.1. Study area**

This study was conducted in Cyili sub-catchment (latitude 02<sup>o</sup>27'14.93" to 02<sup>o</sup>29'51.71"S and longitude 29<sup>o</sup>49'27.53" to 29<sup>o</sup>46'21.7"E) located on Huye and Gisagara districts in the Southern province of Rwanda (Figure 3.1). The catchment has a total area of 430 ha<sup>2</sup> and the elevation ranges from 1350 and 1650 m above the sea level.

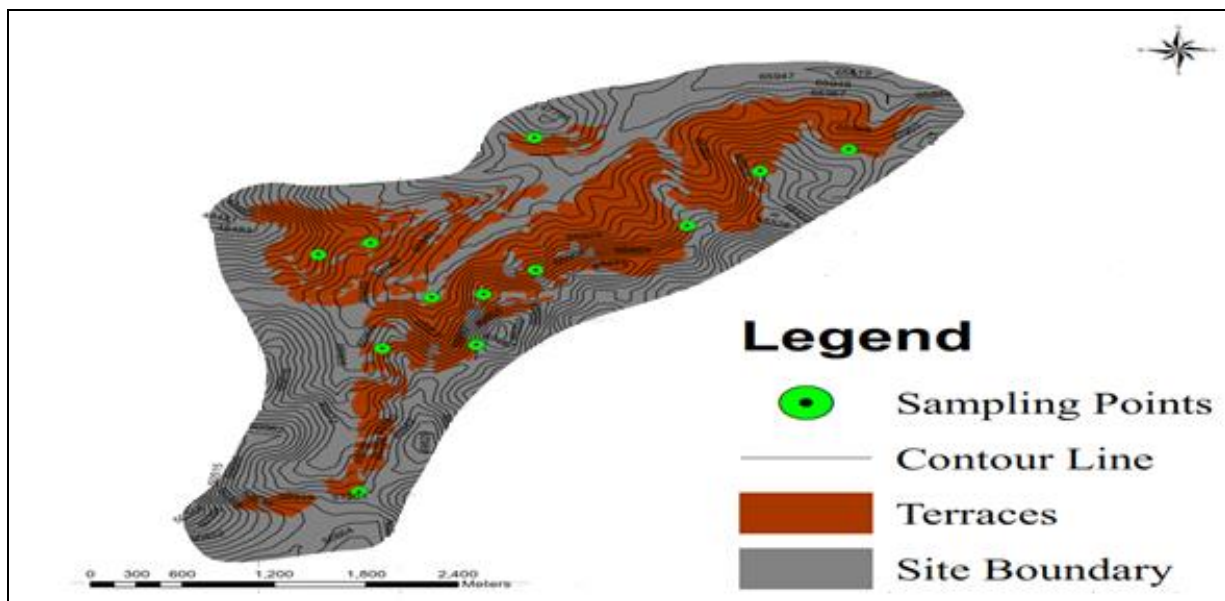


**Figure 3.1: Map of Cyili sub-catchment location**

Cyili sub-catchment is classified as central plateau, middle altitude of Rwanda (Verdoodt and Ranst, 2006). Most of the cultivated lands were conserved with the bench terraces. Catchment land is suitable for cereal crops such as maize (*Zea mays*), rice (*Oryza sativa*), sorghum (*Sorghum bicolor*), root and tuber crops such as cassava (*Manihot esculenta*), sweet potato (*Ipomoea batatas*) and yam (*Dioscorea alata*), grain legumes such as groundnuts (*Arachis hypogaea*) and soybean (*Glycine max*), and fruit trees such as avocados (*Persea americana*) and coffee (*coffea arabica*) (MINAGRI, 2010). The climate of the study area is classified at sub-humid. Rainfall is bimodal, with the long rains in March to May and the short rains in mid-September to mid-December. Annual mean temperature vary between 14.2<sup>0</sup>C minimum to 24.8<sup>0</sup>C maximum (MINAGRI, 2010) .

### 3.2.2. Soil sampling design and data collection

Soil sampling and mapping was conducted in December 2016 and twelve soil profiles randomly selected in the catchment are shown in (Figure 3.2). Soil profile selected were based on the topography of the catchment (top, middle and bottom). Undisturbed soil samples from 0-30 and 30-60cm soil depths were collected for moisture and bulk density determination. Soil samples collected were geo-referenced with the global position system (GPS) and coordinate points imported into a geographic information system (ArcGIS 10.1) to map out the location of the soil profiles in the sub-catchment.



**Figure 3.2: Surface soil moisture sampling points in the study area**

### 3.2.3. Determination of soil moisture content.

Soil moisture content was determined by gravimetric method described by Black *et al.*(1965). The undisturbed soil samples were transferred to the laboratory, weighed and dried in the oven at 105°C for 24 hours to a constant weight. Gravimetric soil water content was obtained as ratio of

the weight loss after drying to the dry weight of the soil sample calculated by using equations 3.1.

$$\text{Gravimetric moisture content (\%)} = \frac{\text{Wet weight soil} - \text{Oven dry weight soil}}{\text{Oven dry weight soil}} \quad [\text{Eqn 3.1}]$$

### 3.2.4. Determination of soil Bulk density

Bulk density was determined using the standard core method as defined by Okelebo *et al.* (2002). The undisturbed soil sample weighed and then dried in oven at 105°C for 72h until the weight become constant. Core ring volume was 98.13cm<sup>3</sup> and Bulk density calculated with Equation 3.2 (Okelebo *et al.*, 2002).

$$\text{Bulk density} = \frac{\text{Oven dry weight soil} - \text{core ring weight}}{\text{volume of core ring}} \quad (\text{g/cm}^3) \quad [\text{Eqn 3.2}]$$

### 3.2.5. Determination of Field capacity and Permanent wilting point

Field capacity (FC) and permanent wilting (PWP) were determined by soil water characteristics method as developed by Saxton and Rawls. (2006) and is available at (<http://staffweb.wilkes.edu/brian.oram/soilwatr.htm>). It was estimated with the soil percentages of sand and clay. The soil total available water (TAW) across the rooting depth (RD) was computed using equation 3.3 adopted from Okelebo *et al.* (2002).

$$\text{TAW} = (\Theta_{\text{FC}} - \Theta_{\text{PWP}}) \text{RD} \quad [\text{Eqn 3.3}]$$

Where,  $\Theta_{\text{FC}}$  = volumetric moisture content at field capacity (volume in %);  $\Theta_{\text{PWP}}$  = volumetric moisture content at permanent wilting point (volume in %); RD = soil layers within rooting (cm) depth,  $\rho_b$  = bulk density (g cm<sup>-3</sup>).

### 3.2.6. Supplementary irrigation water requirement determination

Supplementary irrigation water requirements modeling was carried out using CROPWAT version 8. It is a decision support tool developed by the Land and Water Development Division of FAO (FAO, 1992). The advantage of using CROPWAT computer program tool is reliable and fast to calculate reference evapo-transpiration (ET<sub>o</sub>) using FAO-56 Penman Monteith method (Allen *et al.*, 1998), crop evapotranspiration (ET<sub>c</sub>), crop water and irrigation requirement (FAO, 1992). CROPWAT model requires main dataset as inputs of climatic, cropping pattern and soil data; FAO, 1992). Monthly climatic data of rainfall (mm), minimum and maximum temperatures (°C), relative humidity (%), sunshine (hours) and wind speed (Km/day) were obtained from Rwanda National Meteorological Service recorded from 1971 to 2016. Soil properties such as texture, soil moisture content and bulk density were analyzed in laboratory to allow for calculation of the total available water (TAM) and readily available moisture (RAM).

The rainfall monthly data were used as input to calculate effective rainfall estimated with USDA-SCS, (1967) method. Maize variety ‘PAN53’ was used as test crop due to high yielding potential and adaptation to various agro-ecological zones in Rwanda (Ngaboyisonga *et al.*, 2016). The growing cycle is 125 days with growth stages of 20, 35, 40 and 30 days for initial, development, reproduction and maturity, respectively (Sutcliffe *et al.*, 2016). Root depth, water stress coefficient (K<sub>s</sub>), yield response factor (K<sub>y</sub>) and Crop coefficient (K<sub>c</sub>) value for short rainy season data used was from Rubona research (RAB) station in the same area study and the FAO crop book (FAO, 2012) see appendix 3. To estimate the supplementary irrigation water requirement actual crop evapotranspiration (ET<sub>c</sub>) is required (Allen *et al.*, 1998) and was estimated using Equation 3.4:

$$ET_c = ET_o \times K_c$$

[Eqn 3.4]

Where  $ET_c$  is the crop evapotranspiration,  $ET_o$  is the potential evapotranspiration and  $K_c$  is the crop coefficient. The irrigation scheduling was computed using soil water budget method after the calculation of crop water requirement, net irrigation and the selected irrigation method.

### 3.3. Statistical analysis

The collected data was subjected to statistics analysis to determine data means, standard deviation (SD), coefficient of variation (CV) of soil moisture between top soil and subsoil layers using SPSS, version 16.0. The same statistical software was applied for one-way ANOVA to determine the soil moisture difference between in the top and subsoil layers at 5% level of confidence. The ArcGIS version 10.1 was used to generate a map of the soil moisture variation between top and subsoil layers in the study area.

## 3.4. Results and Discussions

### 3.4.1. Seasonal climatic data in Cyili sub-catchment

Seasonal climatic data and reference evapotranspiration of the study area during short rain are presented in Table 3.1. The minimum and maximum mean temperature were 14.2°C and 25.0°C respectively, which was ideal for optimum maize growth (Singletary *et al.*, 1994). The average  $ET_o$  was 3.35 mm/day while the relative humidity was 72.5%. The seasonal average sunshine was 4.6 and wind speed was 91 km/day. Findings from climatic data presented in Table 3.1 revealed that the Cyili sub-catchment has poor rainfall distribution, thus affecting crop performance and limiting the actual crop evapotranspiration. The  $ET_o$  was low in November and December due to high relative humidity and low temperatures. It was higher in September and February resulted to low relative humidity and the high temperature.



**Table 3 1: Average seasonal climatic data in Cyili sub-catchments from 1971 to 2016**

Country: Rwanda		Station: Rubona		Altitude: 1706m		Lat: 2.46°S Long: 29.76°E	
Month	Min Temp °C	Max Temp °C	Humidity %	Wind Km/day	Sum hours	Rad MJ/m <sup>2</sup> /day	ETo Mm/day
September	14.3	26.0	67	83	5.3	17.5	3.62
October	14.3	25.5	72	81	4.5	16.5	3.42
November	14.0	24.1	80	78	4.3	15.9	3.13
December	14.3	24.4	74	76	4.1	15.4	3.10
January	14.2	24.8	72	81	4.5	16.2	3.29
February	14.2	25.3	70	85	5.0	17.3	3.56
<b>Average</b>	<b>14.2</b>	<b>25</b>	<b>72.5</b>	<b>80.6</b>	<b>4.6</b>	<b>16.5</b>	<b>3.35</b>

This is in agreement with the findings of Haggag *et al.* (2016) who reported that in Rwanda, potential evapotranspiration has been increasing in June and September while decreasing in April and November. Djaman *et al.* (2015) also reported that potential evapotranspiration is very important in irrigated and rainfed agriculture for water management. Climatic parameters including, temperature, sunshine, rainfall, humidity and solar radiation affect plants development (Bouraima *et al.*, 2015). The optimum temperature and sunshine duration are very important to physiological of maize as they increase photosynthesis activity, kneel weight as well as size and accelerate tasseling time (Du Plessis, 2003). Rainfall is reported a climatic factor for growing maize from germination to physiological maturity (Muhammad *et al.*, 2015). This suggests the importance of accurate information on climatic data to ensure agriculture development.

### 3.4.2. Soil moisture variation in Cyili sub-catchment

Table 3.2 show level the soil moisture variation between the soil layers. There was significant increase in soil moisture in the subsoil than in the topsoil. The average soil moisture for the top was 3.54% lower than subsoil 4.81% with the standard deviation of 0.51 for the top and 1.17 in the subsoil. Soil moisture coefficient of variations (CVs) in the top and subsoil were 2.9 and 4.9; respectively. This implies that the soil moisture in the top had less variability than in the subsoil. Clay soil accumulation in the subsoil, the higher evaporation of water on soil surface and vegetation cover transpiration in the top than in subsoil may have attributed to the significance difference observed.

**Table 3 2: Soil moisture content (%) variation along the Cyili sub-catchment**

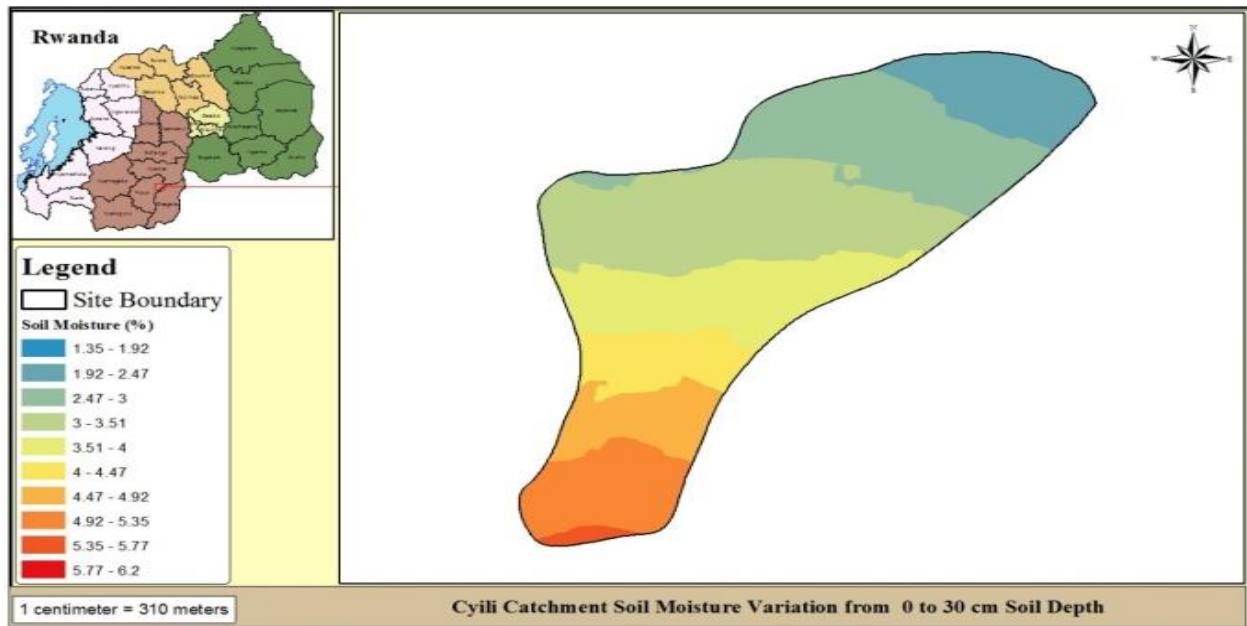
Catchment position	Topsoil (0-30 cm)	Subsoil (30-60cm)	Meam
Top	5.10	6.36	5.73
Middle	2.71	3.96	3.34
Bottom	2.82	4.10	3.46
Mean	3.54	4.81	4.18
LSD 5%	1.77	4.08	
SD	0.51	1.17	
CV%	2.9	4.9	

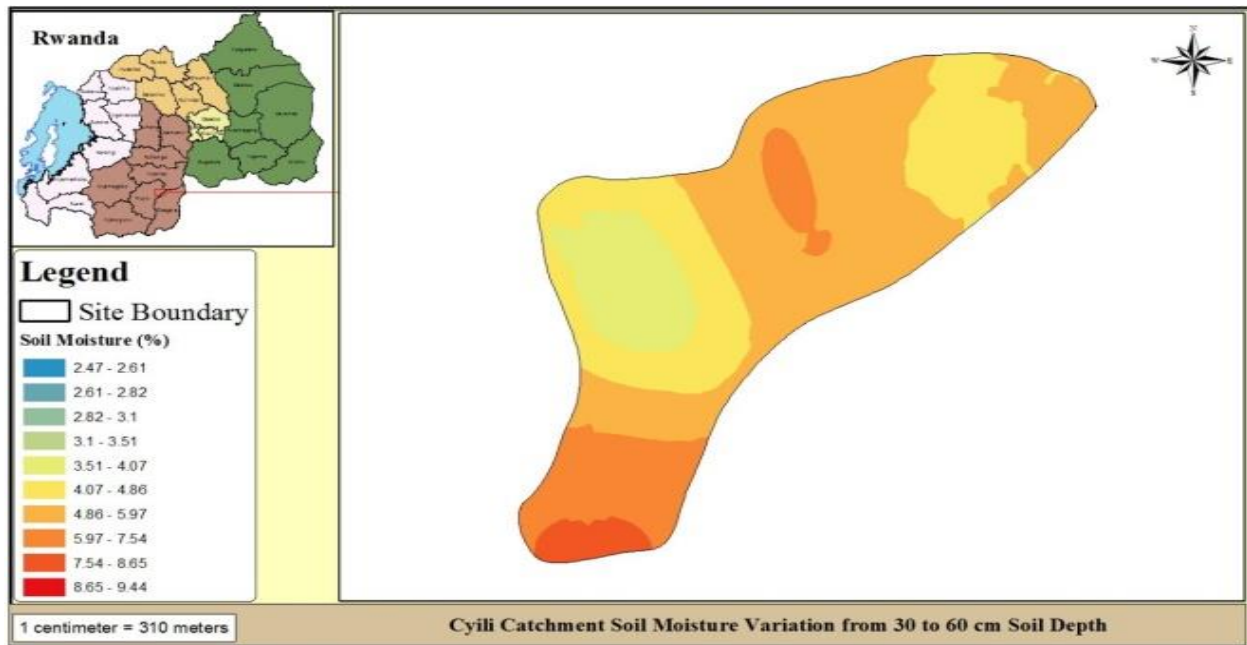
SD: Standard deviation, CV: Coefficient of variations, LSD: Least significance difference

These results agree with, the findings by Rong *et al.* (2017) and Jianping *et al.* (2002) who concluded that the soil moisture was slightly higher in subsoil than in topsoil in Loazhai agricultural catchment, China. According to Rong *et al.* (2017) the variability of soil moisture is relatively higher in mountainous region, than in the landscapes. Cyili sub-catchment is also

located in mountainous region, characterised by heterogeneous topography of which could also result in high variability of soil moisture. The present results corroborate with those of Penna *et al.* (2009) who reported that the variability of soil moisture in the steep alpine (Italian) caused by the topography of higher elevations and steep slope. This suggests that the knowledge of distribution surface moisture content is important to farmers in predicting irrigation and assessing available water for plant growth. It can be used to estimate soil moisture content with depth in the plant rooting zone, where active roots residing in soil is important for crop water absorption and crop yields (Shouqin *et al.*, 2014).

Figure 3.3 shows the soil moisture distribution in Cyili sub-catchment were low in the Northern (lower elevation) and high in the southern (upper) part of the sub-catchment.





**Figure 3.3: Soil moisture variation in Cyili sub-catchment during short rainy season 2016-2017**

This was due to heterogeneity of soil type and land use. Where as in the north part of sub-catchment the dominant soil was cambisols soil, while in the south it was Acrisols characterised by argic horizon depth with clay content known to maintain soil moisture than sand soil (Ilstedt *et al.*, 2000). In addition, agricultural activities in southern part of the catchment were more developed than in the northern part which would probably have lead to more utilization of soil moisture. This was in agreement with the findings by Rong *et al.* (2017) and Qiu *et al.* (2001) who reported that the soil water content in the Laozhai agricultural catchment in China decreased with altitude.

### 3.4.3. Supplementary irrigation water requirement during short rain season

**Error! Reference source not found.** shows that crop coefficient ( $K_c$ ) of maize increased in middle development stage 1.07 in decade 1 as far as 1.08 in decade 2 and 3. The crop evapotranspiration (Etc) increased to 3.36; 3.38 and 3.43mm/day in decades 1, 2 and 3. Irrigation water required to meet the crop water demand was 32.7mm in decade 1 as well as 29.9 mm in

decades 2 and 3. Consequently, effective rainfall decreased from 32.7 to 29.9mm in mid development crop stage. The highest (peak) ETcs of maize was 37.7mm/decade and being 3.43mm/decade in the mid development crop stage. However, irrigation water requirements peak was 7.8mm/decade in December. Maximum effective rainfall was 40.6mm in November and the minimum was 5.5mm in February up to 26.3mm in October. Total effective rainfall during the cropping season was 388.9 mm/decade and supplementary irrigation water requirement for maize crop was 20.5 mm/decade.

**Table 3 3: Crop water requirement for maize during short rain season (2016-2017) at Cyili sub-catchment**

<b>Month</b>	<b>Decade</b>	<b>Stage</b>	<b>Kc</b>	<b>Etc</b>	<b>Etc</b>	<b>Eff.rain</b>	<b>Irr.Req</b>
				<b>mm/day</b>	<b>mm/dec</b>	<b>mm/dec</b>	<b>mm/dec</b>
Oct	1	Init	0.40	1.39	13.9	26.3	0.0
Oct	2	Init	0.40	1.36	13.6	28.6	0.0
Oct	3	Dev	0.52	1.72	18.9	31.8	0.0
Nov	1	Dev	0.72	2.34	23.4	36.7	0.0
Nov	2	Dev	0.92	2.89	28.9	40.6	0.0
Nov	3	Mid	1.07	3.36	33.6	37.3	0.0
Dec	1	Mid	1.08	3.38	33.8	32.7	1.1
Dec	2	Mid	1.08	3.36	33.6	29.9	3.7
Dec	3	Mid	1.08	3.43	37.7	29.9	7.8
Jan	1	Late	1.04	3.37	33.7	30.3	3.4
Jan	2	Late	0.90	2.96	29.6	30.0	0.0
Jan	3	Late	0.74	2.51	27.7	29.3	0.0
Feb	1	Late	0.65	2.25	4.5	5.5	4.5
<b>Total</b>					<b>332.8</b>	<b>388.9</b>	<b>20.5</b>

Dec=December, Init = initial; Dev = development, mid = middle crop development, Kc = crop coefficient, ETC = crop evapotranspiration Eff = effective rain, Irr = irrigation requirements

The findings from the present study revealed that the October and November no supplementary irrigation water was required because of the higher effective rainfall, while December and January supplementary irrigation were needed (Table 3.3). The reason is because there was low rainfall, low relative humidity combined with high temperatures which led to increased evapotranspiration. These findings are in accordance with Haggag *et al.* (2016), who reported in Rwanda that the high rainfall for short rain season was in November while less rainfall was found in December and January. Similar previous studies by Bouraima *et al.* (2015) and Shouqin *et al.* (2014), reported the hottest period resulted in decreased soil moisture and increase in crop water requirements.

Data in table 3.3 show that in December and first week of January, the effective rainfall is less than the crop water requirements and the Etc has increased. This suggests supplementary irrigation is required to satisfy the water requirement of maize and it's an effective method of increasing crop yield in the Cyili sub-catchment. This is in agreement with report of Pandey *et al.* (2013), Van Der Zaag and Gupta. (2008) who suggested that crop require 100mm of water as supplemental irrigation to attain potential yield in semi-arid region.

#### **3.4.4. Irrigation scheduling in Cyili sub-catchment during short rain season**

The present study showed that in December, effective rainfall was low and supplementary irrigation was required to improve crop productivity. However, in October and November, no addition water required at initial and development stage crop because of higher rainfall and lower evapotranspiration. Irrigation suggested to start on 12<sup>nd</sup> and 22<sup>nd</sup> December at mid development stage where farmers should supplement water two times in the interval of 10 days, 3.8mm to

7.8mm (Table 3.4). The highest peak of crop evapotranspiration (ET<sub>c</sub>) was found in December (at development stage). This may be due to the fact that rainfall decreases in December while the crop water consumption increased at this stage. This is in agreement with Karuku *et al.* (2014) who reported that at the development stage of tomato, water depletion increases as crops develop.

**Table 3 4: Irrigation water requirement and irrigation scheduling**

Date	Day	Crop stage	Eta %	Depletions %	Net. Irr mm	Gr. Irr mm	Flow l/s/ha
1 <sup>st</sup> Oct	1	Init	100	61	7.7	11.0	1.27
2 <sup>nd</sup> Dec	63	Mid	100	50	20.2	28.8	0.05
12 <sup>th</sup> Dec	73	Mid	100	50	20.2	28.9	0.33
22 <sup>nd</sup> Dec	83	Mid	100	50	20.3	29.0	0.34
1 <sup>st</sup> Jan	93	Mid	100	51	20.5	29.3	0.34
2 <sup>nd</sup> Feb	Late	Late	0	37	-----	-----	-----

Finally, additional water should be applied on 1<sup>st</sup> and 2<sup>nd</sup> February with 3.4mm to 4.5mm, respectively due to low rainfall and higher crop evapotranspiration (Table3.4). The late crop stage in February, no irrigation required because of the evapotranspiration decline. Data presented in **Error! Reference source not found.** shows that the total effective rainfall and Net irrigation water requirement in the study area were 246.9mm and 88.9mm respectively. Total rainfall during the short rain cropping season was 476.7mm. However, 229.7mm of rainfall were lost as runoff and evaporation. Supplementary irrigation water required (gross irrigation) during short rain season was 127mm (1,270m<sup>3</sup>/ha/season). Similar study by Jabloun and Sahli, (2007) found that in the late stage, evapotranspiration and depletion decline. This suggests proper

irrigation scheduling supports the farmers to apply water more efficiently while taking into account crop evaporation and rainfall

**Table 3 5: Irrigation scheduling development**

Total gross irrigation 127.0mm	Total Rainfall 476.7mm
Total net irrigation 88.9mm	Effective Rainfall 246.9mm
Actual water use by crop 330.6mm	Total rain loss 229.7mm
Potential water use by crop 330.6mm	Moist deficit at harvest 14.8mm
Efficiency irrigation schedule 100%	Actual irrigation requirement 83.6mm

However, at small scale farming, irrigation scheduling can not be applied in a practical manner as they require sophisticated monitoring equipment and data processing. In addition, the development of irrigation calendars requires a good knowledge of the meteorological conditions in the study area, especially the reference evapotranspiration (ET<sub>o</sub>) and rainfall (Jabloun and Sahli, 2007).

### **3.5. Conclusions and recommendations**

In conclusion, this study revealed that the Cyili sub-catchment need an additional amount of water (88.9 mm) in December and January to improve crop productivity. In October and November no irrigation is required due to the available rainfall and low crop evapotranspiration during that period. The present findings suggested two applications of irrigation at the interval of 10 days during main crop development stage. The farmers should ensure that water applied to the crop will be more beneficial and should be applied intelligently to the root zone in the right quantity. Soil moisture was low in northern part compared to the southern Cyili sub-catchment and was significantly higher in the subsoil than in the topsoil. Getting a map of the soil moisture



variation is very crucial and would help the in-situ rainfall use and rain water harvesting in the hillsides area of Cyili sub-catchment.

## CHAPTER FOUR

### SURFACE RUNOFF VOLUMES GENERATED FROM THE CYILI SUB-CATCHMENT OF RWANDA DURING THE SHORT RAIN SEASONS

#### **Abstract**

Runoff farming is reported to improve arable land productivity and crop yields. The purpose of this study was to assess available rainwater that can be harvested in Cyili sub-catchment during short rain season. Geographical information system and ArcGIS version 10.1 were used to delineate the study area. The average daily rainfall data recorded from 1971 to 2016 was used to determine return period and probability of occurrence. Data on land cover/use and Soil Conservation Service-Curve Number method (SCS-CN) were applied to estimate volume of surface runoff to be harvested. Result obtained through the digital elevation model analyses indicate that Cyili sub-catchment is comprised of higher elevation variability (1410-1795m) and the slope gradient ranging from 16% to slightly above 60%. Based on Hazen model the return period of lower rainfall (dry spell) event would be expected in 2 years and 98.27% probability of occurrence. The expected seasonal surface runoff volume to be harvested by the farmers was 3,008.5m<sup>3</sup>/ha/season and 1.29km<sup>3</sup>/season for the entire whole sub-catchment (430ha). This suggests that rainwater harvesting through supplementary irrigation is feasible for improving crop production under drought conditions.

**Keywords:** Runoff; Curve number; Arc GIS; Cyili sub- Catchment; Rwanda

#### 4.1. Introduction

World population is growing every year is not proportionally to natural resources land and water (Nazareth., 2016). Sub-Sahara Africa is one of a continent having the shortages of water and food caused by climate variability (Rockstr and Falkenmark, 2015). Rwanda has the potential yield of runoff and receive relatively high average annual rainfall (1200mm) compared to sub-Sahara Africa countries (Malesu *et al.*, 2010). Previous study by Karamage *et al.* (2016) found that the Rwanda mean runoff depth increase by 2.33 mm every year (0.38%) three times more in the rainy season than in dry season. Surface runoff provides suitable environments for numerous types of ecosystems, cycling of chemical and freshwater in the forest area (Klimaszyk *et al.*, 2015), irrigation in agricultural and water for the hydroelectric power plants (Muthu and Santhi, 2015).

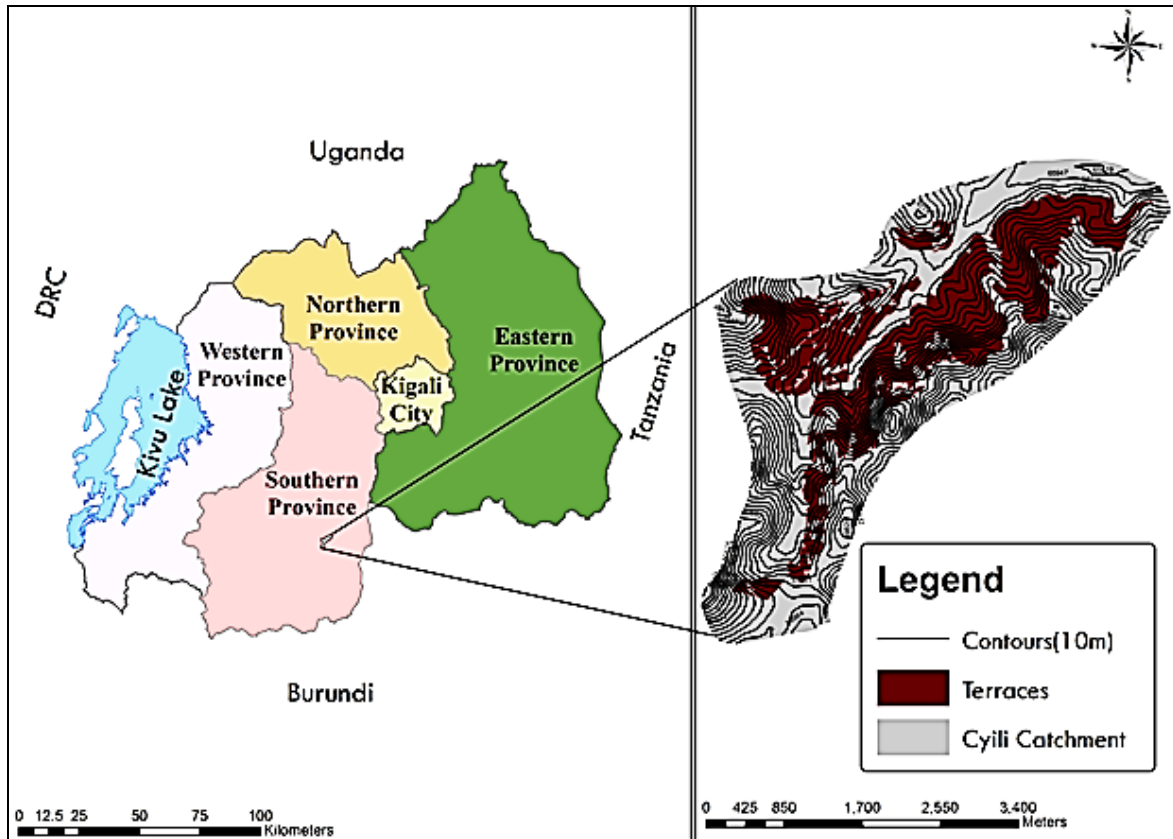
Adoption of rainwater harvesting is required to improve farming activities during dry season in Rwanda. There are numerous models available to estimate runoff. These are Horton infiltration methods (Horton, 1933) used for estimating overland flow water catchment; the Kinematic Wave Method (Lighthill and Whitham, 1955) for estimating runoff from the complex urban areas and size of watershed; Ration Coefficient Methods (Munyaneza, 2014; Thompson, 2006) for smaller catchments (<25km<sup>2</sup>) and Curve Number methods of the Soil Conservation Service Curve Number (SCS-CN) developed by the United Stated Department of Agriculture (USDA). Is commonly and popular method used for the direct measurement surface runoff in long-term (USDA, 1986; Muthu and Santhi, 2015) and was used in this study because it's easy to apply and consider all catchment factors' which influence runoff volume, such as soil type, land use, hydrologic condition, and antecedent moisture condition.

Catchment runoff yield indicates available runoff in a catchment and is influenced by climatological factors (rainfall intensity, antecedent soil moisture, evapotranspiration, etc ) and physiographical factors (stream slope and density, land slope and cover/ land use, soil type, underlying geology, elevation,) (He *et al.*, 2013; Price, 2011). The government of Rwanda has set vision 2020 (MINECOFIN, 2012) is to develop the available water resources for sustainable agricultural production and economic growth (MINAGRI, 2013). Cyili sub-catchment is one of a selected catchment in 2012 by the Ministry of Agriculture to improve land productivity through soil conservation (bench terrace). Nevertheless, there is a challenge of unpredictable rainfall in short rainy season, between September and January, and associated lack of techniques to harvest rainwater which is lost through surface runoff. Prediction and comprehensive information on the runoff generated in agriculture catchment in terms of the quantity under farming is necessary for water management. The purpose of this study is to quantify the surface runoff volume generated in Cyili sub-catchment for crop production during short rainy season.

## **4.2. Materials and Methods**

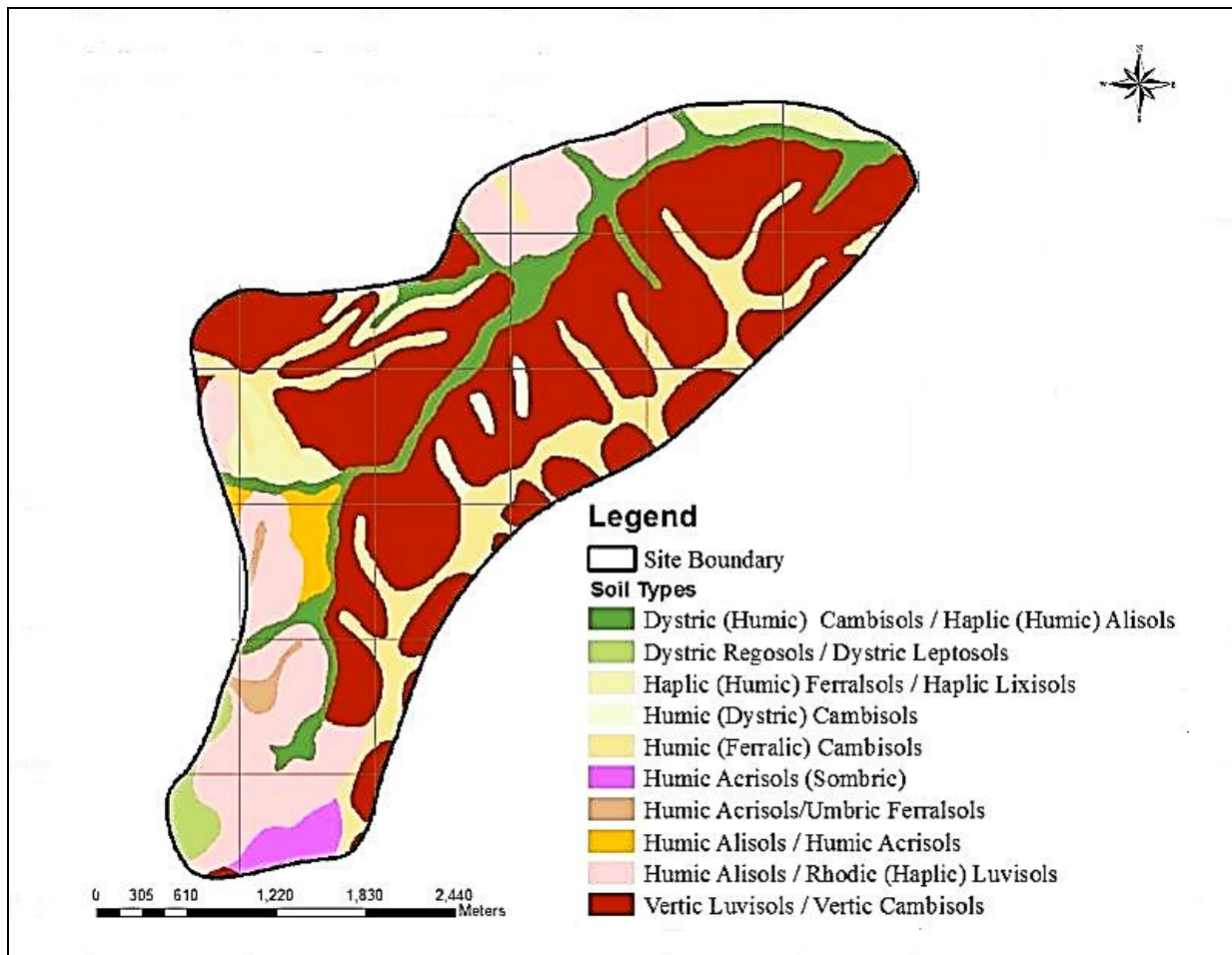
### **4.2.1. Study area**

The study was carried out in Cyili sub-catchment (latitude 0<sup>0</sup>27'2" S to 0<sup>0</sup>30'2"S and longitude 30<sup>0</sup>46'29"E to 30<sup>0</sup>49'29"E), located between Huye and Gisagara districts of the Southern province of Rwanda, 149 Km from Kigali city. The altitude vary between 1410 to 1795m above the sea level and most of the cultivated land is on steep slopes. The Cyili sub-catchment has an area of 430ha with 1,114 farmers of comprising of 530 men and 584 women (MINAGRI, 2010).



**Figure 4 1: Map of Cyili sub-catchment location**

The dominant soil types are Vertic Luvisols, Humic Alisols, Dystric (humic) and Humic (ferralic) Cambisols (Figure 4.2) as classified by the FAO soil classification (FAO/UNESCO, 2003). The catchment is suitable for cereal crops such as maize (*zea mays*), rice (*Oryza sativa*), sorghum (*Sorghum bicolor*), root and tuber crops such as cassava (*Manihot esculenta*), sweet potato (*Ipomoea batatas*) and yam (*Dioscorea alata*), grain legumes such as groundnuts (*Arachis hypogaea*) and soybean (*Glycine max*), and fruit trees such as avocados (*Persea americana*) and coffee (*coffea arabica*) (MINAGRI, 2010).



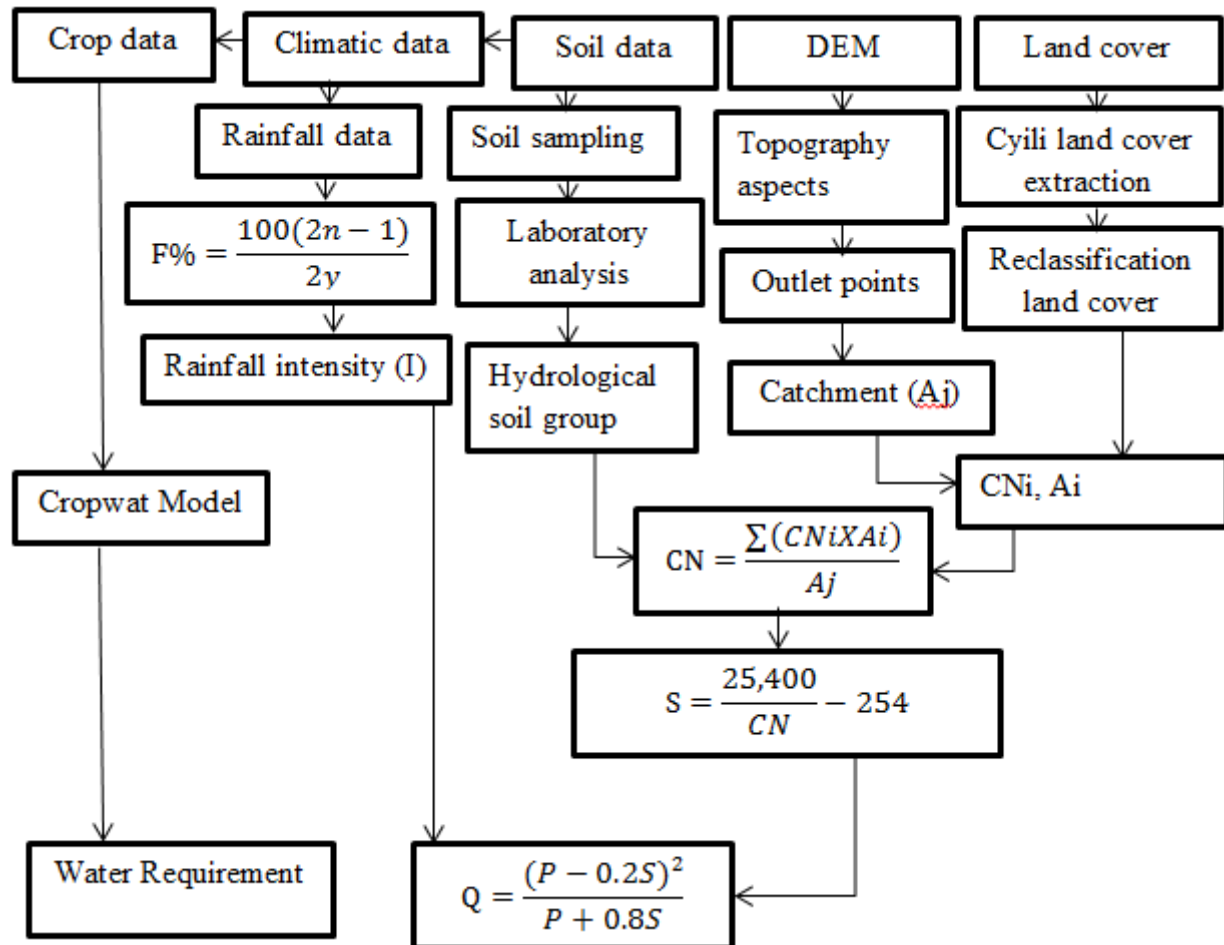
**Figure 4 2: Soil classification map of Cyili sub-catchment**

The climate of the study area classified in sub-humid and belong to Mayaga agro-ecological zone (IX) with extreme spatial and temporal rainfall distribution (Verdoodt and Van Ranst, 2006) and receives an annual rainfall of 1,141.1 mm. Rainfall is bimodal with the long in March to May and the short in mid-September to mid-December. An annual mean temperature ranges from 14.2<sup>0</sup>C to 24.8<sup>0</sup>C (MINAGRI, 2010).

#### **4.2.2. Model Development and data collection**

To determine the surface runoff water in a catchment with SCS-CN method depends on many factors including soil types, land use and cover and the antecedent soil moisture (Viji *et al.*,

2015). The major steps used to determine the surface runoff volume and water requirement are summarized in Figure 4.3.



**Figure 4 3: A flowchart used for modeling potential runoff and water requirement in Cyili sub-catchment**

The surface runoff volume was computed using curve number method (equation 4.1) developed by the Soil Conservation Service Curve Number (SCS-CN) of the United States Department of Agriculture (USDA, 1986) as given in Equation 4.1

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad \text{[Eqn 4.1]}$$

Where, Q = the runoff volume (mm); P = Average daily precipitation (mm); S = potential maximum retention after runoff begins (mm) and is correlated to the soil and cover situations of catchment NRCS. (2004) as given in Equation 4.2

$$S = \frac{25,400}{CN} - 254 \quad \text{[Eqn 4.2]}$$

The curve number (CN) was computed on the basis of the hydrological soil group and land cover of the study area. The high values of CN implies higher potential generation of runoff and has a range of 0 to 100 (NRCS, 2004).

#### 4.2.3. DEM for catchment delineation

Catchment boundary was delineated using the Digital Elevation Model (DEM) within the ArcGIS10.1. The topography was extracted from the DEM information obtained from the Centre for Geographic Information System (C-GIS) at the University of Rwanda and was described in terms of slope, aspect and elevation.

#### 4.2.4. Classification of land use and land cover

Land use/cover update map of Rwanda, 2016 available at the Rwanda Natural Resource Authority (RNRA) and Regional Centre for Mapping of Resources for Development (RCMRD) was used to extract the land cover of the study area. The land use/cover map of the catchment area was obtained after digitalizing the surface area ( $A_i$ ) occupied. The land use/cover of the study area was classified into four classes and includes agriculture, forest, shrub and coffee plantation, after the field inspection of the actual land use and soil characteristics. The cover number (CN) is a function of soil type and land cover (Viji *et al.*, 2015). The appropriate CN value was estimated using the corresponding NRCS.TRR.55 lookup tables (USDA-NRCS, 1986) and weighted CN value of the whole catchment was computed manually using equation 4.3

$$CN = \frac{\sum(CN_i X A_i)}{A_j} \quad \text{[Eqn 4.3]}$$



Where, CN: Curve number, CNi: Adjusted curve number, Ai: Adjusted area (ha) and Aj: Total area (Ha)

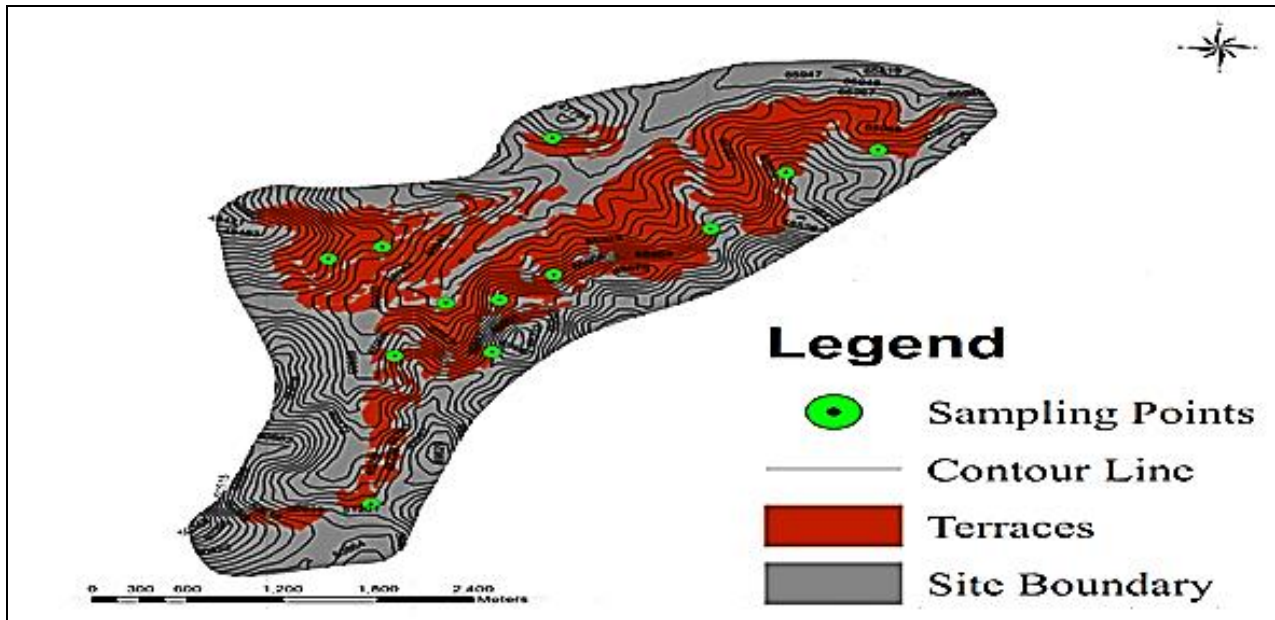
The value of CNII is the average annual condition for high and lower runoff prediction associated with Antecedent Moisture Content II (AMC-II) condition. The CN values for AMC-I (dry condition) and AMC-III (wet condition) were calculated using equations 4.4 and 4.5 as defined by (Viji *et al.*, 2015; Schiariti, 2010)

$$CNI = \frac{4.2CNII}{(10-0.0588CNII)} \quad \text{[Eqn 4.4]}$$

$$CNIII = \frac{23CNII}{(10+0.13CNII)} \quad \text{[Eqn 4.5]}$$

#### 4.2.5 Soil data and Hydrological Soil Groups

Soil texture for the study area were extracted from the existing soil survey map of Rwanda made by the University of Gand (Belgium), Department of Geology and Pedology from 1981 to 2000 which is digitised and interpreted. The soil texture of the country was classified into four main classes based on the USDA triangle of soils textures (Benimana *et al.*, 2015). The soil types in Cyili sub-Catchment was linked to the country pedological map after digitization and each polygon of the soil map was classified into the Hydrologic Soil Groups (Group A-D) according to the NRCS.TRR.55 lookup tables reference (USDA-NRCS, 1986). Soil texture of the catchment was determined in laboratory using hydrometer method defined by Bouyoucos (1962) based the USDA textural triangle. The soil texture samples were randomly collected from 0-30cm and 30-60cm in the soil profile according to the topography and landscape of the Cyili sub-catchment (top, middle, and bottom), shown in figure 4.4.



**Figure 4 4: Soil texture sampling points in the study area**

#### 4.2.6. Climatic

Cyili sub-catchment is located near Rubona Meteorology Station used for climatic data. The daily rainfall data recorded from 1971 to 2016 were collected from the Rwanda Meteorological Department Services and were used to determine effective rainfall and to plot the probability of occurrence using the Hazen equation (USDA-SCS, 1967) as given in Equation 4.6 and 4.7

$$F\% = \frac{100(2n-1)}{2y} \quad \text{[Eqn 4.6]}$$

$$\text{Return Period} = \frac{100}{F\%} \quad \text{[Eqn 4.7]}$$

Where, P%: is the probability of occurrence; n: rank of each event the rainfall; y: the total numbers of each event the rainfall events.

#### 4.2.7. Crop data

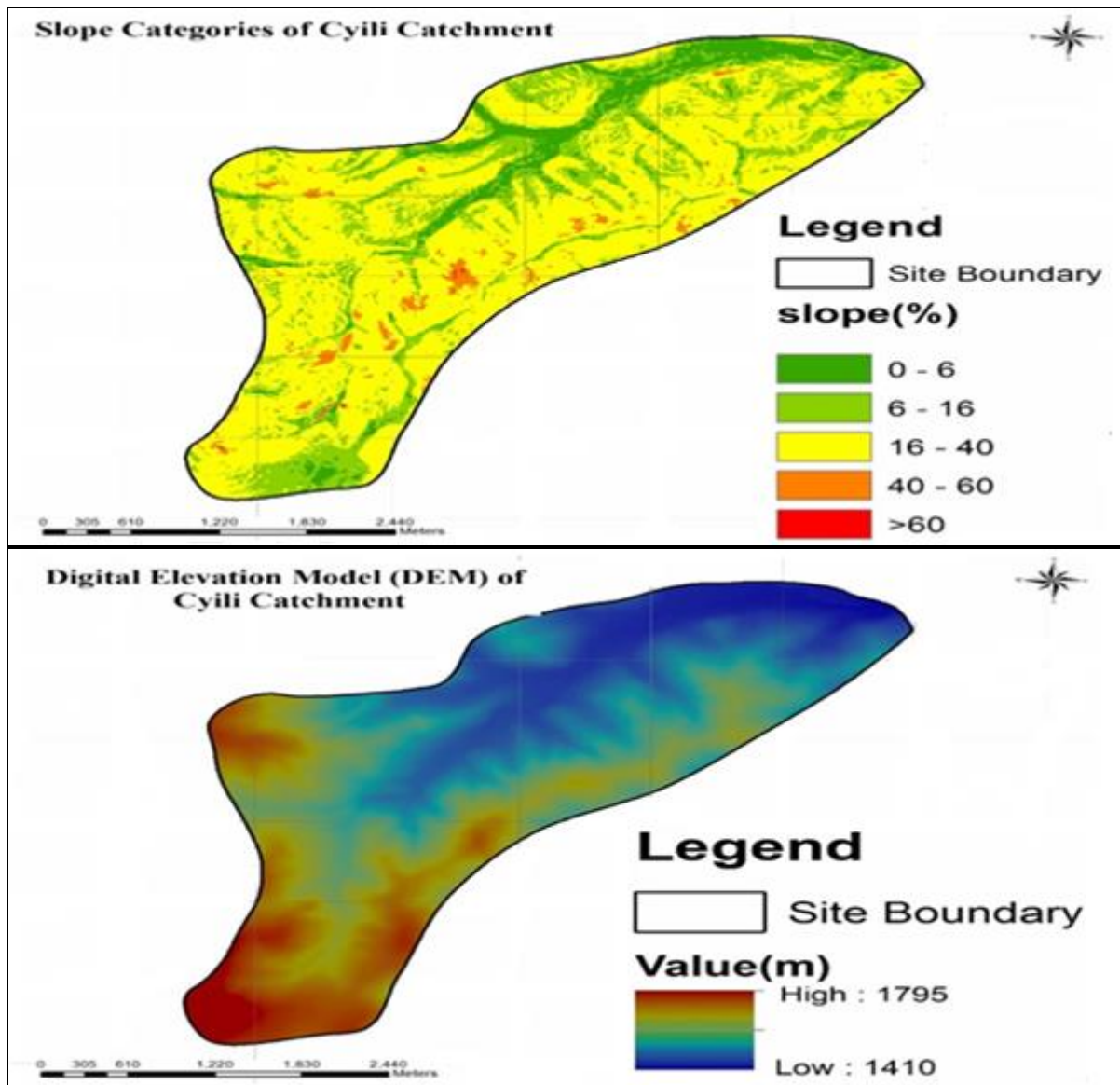
Maize (*Zea mays*) variety ‘PAN53’ was used as test crop. The crop data needed to determine crop water requirement are planting date; crop growth cycle, crop factors, reference

evapotranspiration (ET<sub>o</sub>), yield response factor, rooting depth and allowable depletion levels were assessed (explained in chapter 5).

#### **4.4. Results and Discussions**

##### **4.4.1. Catchment delineation**

Assessment of the topography, elevation and triangular irregular network (TIN) is necessary for understanding the morphological and hydrological development of the catchment. The topography and elevations presentation in Figure 4.1 show that Cyili sub-catchment elevations vary between 1410 m in North to 1795 m in the Southern part of the catchment. The minimum slope is between 0 to 6%, average slope change is from 16 to 40% and the highest slope is 60%. Figure 4.5 show that the areas of the low elevation (1410-1452.22m) may be flooded during heavy rainfall period.

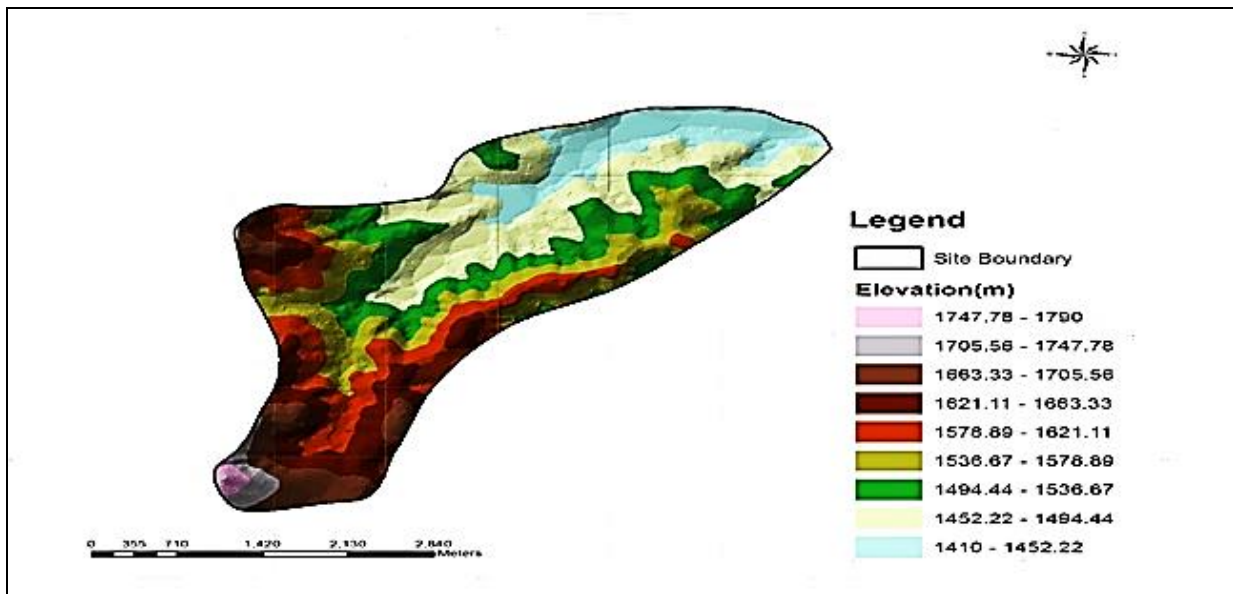


**Figure 4 5: Topography elevation of Cyili sub-catchment**

The high elevation and slope of Cyili sub-catchment indicate irregular network for the hydrological processes. These is in agreement with the findings by Hallema *et al.* (2016); Ragetti *et al.* (2016) and Grünwald *et al.* (2014) who reported that the elevation and slope may govern the stability of catchment and control the quantity and distribution patterns from precipitation as well as change of downstream water supply in the catchment. Ouma and Tateishi (2014) reported that the slope of the catchment may control the duration of the overland flow,

infiltration and subsurface flow. In general, the steep slope hastens runoff and erosion while low slope hastens flooding (Hallema *et al.*, 2016). The Cyili sub-catchment is dominated by higher slope of above 16% and thus prone to erosion. This is in agreement with the findings of Verdoodt and Ranst, (2003) who reported that the land slope between 13-25% in Rwanda was sensitive to erosion classified in class 5 for land suitability.

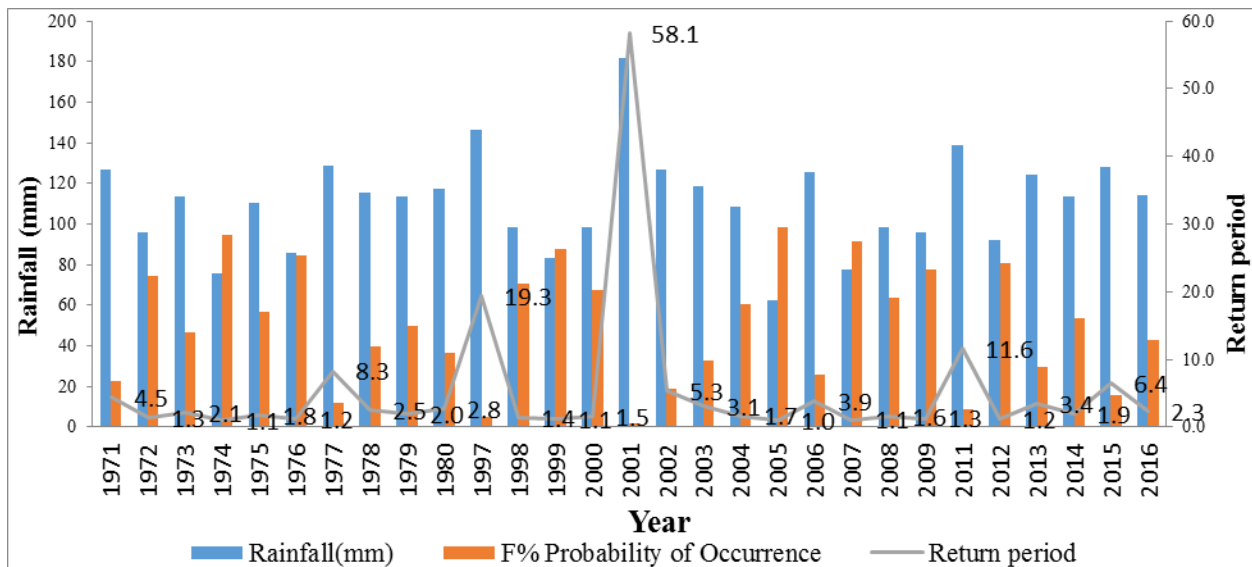
Figure 4.2 show that water in catchment flows from the areas of high elevation (1795 m) to the areas of low elevation (1410 m). The northern part of catchment may have the risk of flooding because of the low elevation (1410m). However, human activities (agriculture and land clearing) may increase flooding in the catchment (Jalil *et al.*, 2006). This suggests that the farmers in Cyili sub-catchment must design and strengthen properly the waterways, hydraulic structures which were constructed by the Rural Sector Support Project (RSSP) to mitigate the flooding.



**Figure 4 6: Cyili sub-catchment Triangulated Irregular Network**

#### 4.4.2. Catchment Rainfall Distribution

It is necessary to have reliable and accurate information on the rarely extreme events of rainfall in terms of flood and dry spell risks in catchment for better water resources management (Munyaneza, 2014; Maraun *et al.*, 2010; Maathius *et al.*, 2006). The average rainfall, probability of occurrence and return period was estimated using Hazen method (Eqn 4.6 and 4.7). The rainfall distribution presented in figure 4.7 shows that the maximum peak of rainfall was 182.4mm in 2001 and the probability of occurrence was 1.72% in the return period of 58years. The minimum rainfall was 62.5mm in 2005 and the probability of occurrence was 98.27% in the return period of around 2years.



**Figure 4 7: Cyili sub-catchment rainfall distribution in short rains seasons**

This shows that there has been poor distribution of the rainfall in the catchment. This is in agreement of Haggag *et al.*(2016) who studied the perception of precipitation for climate change in Rwanda reported that the country has the variability and uneven distribution of rainfall. Seasonal average rainfall is the heart for controlling agricultural yield while low and extreme rainfall can damage crops ( Ceglar *et al.*, 2016; Maraun *et al.*, 2010; Rosenzweig *et al.*, 2001).

Therefore, in the Cyili sub-catchment, farmers should adopt watershed management and water conservation practices that mitigate dry spell problems which likely to occur once in 2years. Flooding event are very rare happens as it may occur after above 50 years.

#### 4.4.3. Catchment volume of Runoff volumes

##### *Catchment Hydrological Soil Groups Classification*

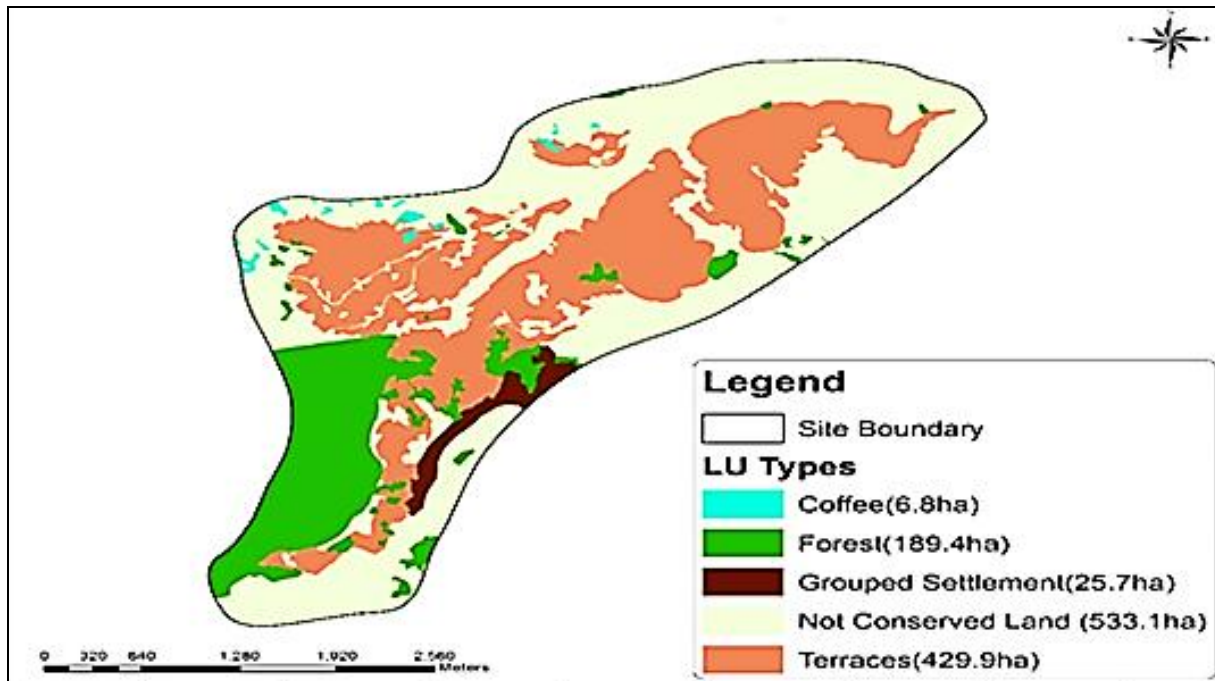
Laboratory soil texture analysis revealed that the dominant soil textures were; sand clay and sand clay loam (figure 4.2). The main soil types of catchment were Luvisols, Alisols, and Cambisols indicated in Figure 4.2. The hydrological soil groups of the Cyili sub-catchment was dominated by the group D (373.8ha) and C (663.2ha) with the high potential to moderate potential of the runoff, respectively. The group B (147.9ha) of low-moderate runoff was found in the north of the catchment while Group A was not found in the catchment.

##### *Catchment land cover computation*

Table 4.1 show that the dominant land use/cover in the catchment is conserved agriculture with 429.9 ha followed by non-conserved agriculture with 533.1 ha and then coffee plantation with 6.8ha.

**Table 4 1: Hydrological soil groups and soil texture of Cyili sub-catchment**

<b>Soil type (FAO Classification)</b>	<b>Soil Texture (USDA)</b>	<b>Hydrologic Soil groups</b>
Humic (Dystric) Cambisols	Silt loam, loam	<b>B:</b> Moderate infiltration rates leading to moderate runoff potential
Dystric Regosols/Leptsols; Haplic Lixisols; Humic Acrisols, Haplic Ferralsols	Sand clay loam	<b>C:</b> High/moderate runoff potential due to slow infiltration rates
Haplic (Humic) Alisols; Rhodic(Haplic)Luvisols, Vertic Luvisols	Sand clay	<b>D:</b> High runoff potential with very low infiltration rates



**Figure 4 8: Land use in Cyili sub-catchment**

The land use and soil type of the catchment were computed to find the weighted CN values with the standard lookup table from NRCS.TRR.55. In calculating surface runoff volume, antecedent soil moisture III (AMCIII) for a wet period (short rainy season) was considered. Data given in table 4.2 show the catchment has the potential to generate runoff volume of 451.27mm (4,512.7m<sup>3</sup>/ha/season) in short rain season.



**Table 4 2: Weighted Curve Number values and runoff volumes of Cyili sub-catchment**

Soil cover complex	Surface Area(ha)	Curve Number (CNi)			CNiX <sub>Ai</sub>		
		AMCI	AMCII	AMCIII	AMCI	AMCII	AMCIII
B:agr no conserved	87.1	64	81	92	5574.4	7055.1	8013.2
B:agr conserved	31.5	52	71	86	1638.0	2236.5	2709.0
B: forest land	29.3	40	60	78	1172.0	1758.0	2285.4
C:agr no conserved	262.3	75	88	95	19672.0	23082.4	24918.5
C: agr.conserved	282.8	60	78	90	16968	22058.4	25452.0
C:coffee plantation	4.7	66	82	92	310.2	385.4	432.4
C: forest land	113.4	54	73	87	6123.6	8278.2	9865.8
D:agr no conserved	183.7	80	91	97	14696.0	16716.7	17818.9
D:agr conserved	115.6	64	81	92	7398.4	9363.6	10635.2
D:coffee plantation	2.1	72	86	94	152.2	180.6	197.4
D:forest land	46.7	62	79	91	2895.4	3689.3	4249.7
D:Settlement	25.7	72	86	94	1850.4	2210.2	2415.8
<b>Total</b>	<b>1184.9</b>				<b>78451</b>	<b>97014.4</b>	<b>108993</b>
Weighted Curve Number (CN)					66	82	92
Potential maximum retention (S)					130	56	22
<b>Direct runoff volume (mm)</b>						<b>1076.27</b>	<b>451.27</b>
<b>Runoff Volume (m<sup>3</sup>)</b>						<b>10762.7</b>	<b>4512.79</b>

Ai: Adjusted area, CNi: Adjusted curve number, CN: Curve number, AMCI: Antecedent moisture content for dry period, AMCII: Antecedent moisture content for average annual condition, AMCIII: Antecedent moisture content for a wet period, P: Average daily precipitation (mm)

According to Benimana *et al.* (2015) and UNEP (2009), all runoff volume generated in the catchment is not used for agriculture. A third (1/3) of it runoff should be part of the environment's protection. The rest runoff volume 300.85 mm (3008.5m<sup>3</sup>/ha/season) can be used by the farmers for crop production. The present results corroborate with the findings of Karamage *et al.* (2016) who reported that the five districts of Rwanda (Rubavu, Nyabihu, Ngororero, Gakenke, and Musanze) may generate, 3.9 km<sup>3</sup> runoff volume in wet season. Benimana *et al.* (2015) in their study in Bugesera district, reported that the runoff water volume that could be harvested was 880 x 10<sup>6</sup> m<sup>3</sup> per day. The low volume of runoff reported in the present study could be due to the fact that the study focused only on the short rainy season while Karamage *et al.* (2016) and Benimana *et al.* (2015) considered on annual rainfall in different

agro-ecological zones. The present results also corroborate with those findings by Rockstr and Falkenmark (2015) who reported that annual average rainfall runoff in sub-Sahara Africa is between 100-300 mm.

#### 4.4.4. Catchment rainfall water balance

That data presented in table 4.3 shows the difference between crop water demand and the effective rainfall in short rain season (October 2016 to January 2017). The seasonal effective rainfall was 246.9mm while, the actual water use for maize crop was 330.6mm therefore there was a deficit of crop water requirement. Consequently, catchment received 476.7mm of rainfall, but 229.8mm was a lost. The water required (gross irrigation) to supplement maize was 127mm while the highest peak periods of irrigation water demand was in December (86.7mm), inverse in November on irrigation required due to the higher rainfall (151.4mm) and the lower value of the ETo was 3.13mm/day as well as the Etc was 2.86mm/day. The total season runoff volume the farmers should harvest was 300.85mm (3008.5m<sup>3</sup>/ha/season).

**Table 4 3: Seasonal rainfall water balance of Cyili sub-catchment**

<b>Month</b>	<b>October</b>	<b>November</b>	<b>December</b>	<b>January</b>	<b>Total</b>
Rainfall(mm)	104	151.4	112.7	108.7	476.7
Eff. rainfall(mm)	54	78.5	58.4	56	246.9
Rainfall loss(mm)	50	72.9	54.3	52.7	229.8
ETo(mm/day)	3.42	3.13	3.10	3.29	16.5
Etc(mm/day)	1.49	2.86	3.41	2.95	15.91
Gross. Irr.Req (mm)	11.0	0	86.7	29.3	127
Runoff(mm)	66	95	71	68	300.85
Extra Runoff after Irr.	55	95	-15.7	38.7	173

ETo = crop evapotranspiration; Eff = effective rainfall, Gr.Irr.Req = Gross irrigation water requirements,

Understanding water balance of a catchment is very important for decisions making strategies in agriculture. The present findings revealed that the seasonal rainfall runoff generated in Cyili sub-catchment was enough to satisfy crop water requirement if the farmers adopt rainwater harvesting. This is in agreement with reports by Karamage *et al.* (2016) and Benimana *et al.* (2015) who reported that the runoff generated from rain season in Rwanda may adequate irrigate the crops for five months during dry season (June to September). Wisser *et al.* (2010) reported that the regions in Africa and Asia with lower rainfall and yield the construction of a small dam may increase the yield above 36%. The present study found that more than half rainfall water received in Cyili sub-catchment was lost as runoff (229.8mm) and effective rainfall (246.9mm) was lower than the actual crop water requirement (330mm) for maize. This deficit of water was caused by the poor management of water resources.

The present results collaborates with those of Malesu *et al.* (2010) who reported that Rwanda receives higher amount of annual rainfall (28km<sup>3</sup>) compared to the sub-sahara Africa countries, but more than two third (2/3) was lost as runoff water (4.3 km<sup>3</sup>), evaporation (9.5km<sup>3</sup>), transpiration (5.3 km<sup>3</sup>), percolation into the groundwater (4.3 km<sup>3</sup>) and 4.8 km<sup>3</sup> for other water consumers (MINIRENA, 2015). Rockstr and Falkenmark (2015) also reported that in sub-Saharan Africa, more than half of rainfall water is lost as runoff (10-25%), transpiration (15-30%) and groundwater (10-30%). The recommendation to farmers in drought prone agro-ecological zones is to adopt rainwater harvesting in order to supplement crops in periods of the dry spell.

#### **4.6. Conclusions and recommendations**

Understanding the quantity of surface runoff generated in a catchment is very important for decision making in agriculture. The purpose of the study was to determine surface runoff volume and water balance generated in Cyili sub-catchment during short rains seasons. The current study showed that Cyili sub-catchment has higher potential runoff volume to stabilize the deficit of water demand in the period of short rainy season. Consequently, more than half of rain water was lost as runoff. This suggests that integrated watershed management and rainwater harvesting is a promising option to stabilize water deficit and to improve crop productivity in Cyili sub-catchment. The higher elevation and slope of Cyili sub-catchment has been affecting the hydrology processes. Flood risk zone of catchment was found to be at the north with lower elevation compared to southern part of the catchment. The farmer's in the northern part of catchment must cultivating with furrow ridge and cleaning properly the waterways and hydraulic structures that have been constructed by the ministry of Agriculture for mitigate the period of flooding.

## CHAPTER FIVE

### THE EFFECT OF RIDGING, MULCHING AND SUPPLEMENTARY IRRIGATION ON MAIZE YIELD IN CYILI SUB-CATCHMENT DURING THE SHORT RAIN SEASONS

#### Abstract

Maize (*Zea mays L.*) is an important cereal crop for food security in East Africa. However, unpredictable rainfall constitutes a remarkable challenge to the stabilisation of maize production. This study was conducted to assess best agricultural practice that can give maximum maize productivity in drought prone agro-ecological zone. The experiment was conducted in Cyili sub-Catchment in Southern Province of Rwanda which is characterized by poor rain. The experimental design consisted of a completely randomized design (CRD) and each treatment (rainfed, contour ridges, ridges + mulching and ridges + supplemental irrigation) was replicated three times. Findings from this study revealed that the maize grain yield and yield components such as plant height, cob diameter and length, number of leaves, 100grains weight, yield per plant were affected highly significantly ( $P < 0.001$ ) by water conservation methods except germination rate which was not significant ( $p > 0.05$ ). Ridges plus supplementary irrigation treatment significantly increased maize yield production to 11,982kg/ha followed by ridges plus mulching (8,089 kg/ha). Ridges produced 5, 937 kg/ha and rainfed plots which were considered as control gave yielded 4,755 kg/ha. Based on Pearson's correlation coefficients, grain yield and yield components were positive correlation and ( $p < 0.001$ ) under various water conservation methods. Ridges plus supplementary irrigation through rainwater harvesting was found to be a more promising option for maize growers, to mitigate dry spell and stabilize maize production in rainfall deficient agro-ecological conditions in Rwanda.

**Keywords:** Maize yield, mulching; ridge; short rain season, supplementary irrigation.

## **5.1. Introduction**

Drought is one of the most hazard from climate change which frustrates the productivity of agricultural crops (Muhammad *et al.*, 2015). Agriculturalists define drought as a prolonged period of short precipitation resulting for water deficiencies and lack of soil moisture to support crop production (Solh and Van Ginkel., 2014). Hydrologists define drought as a prolonged period of average precipitation which generate the natural available water (e.g. river, lake, groundwater) (Tate and Gustard, 2000). Every year there is a loss of 25% crop yield globally caused by severe drought (Bankole *et al.*, 2017). It is estimated that about 36 million people in sub-sahara Africa are experiencing severe food shortage because of the drought (WaterAid, 2017; Nazareth, 2016).

Globally, maize crop is ranked as third important cereal crop consumed after wheat and rice (Olaniyan, 2015) and first productive cereal crop (FAOSTAT, 2015). Maize is an important food crop in sub-sahara Africa 300 million people in this region use maize as the primary source of food crop and livelihood (Macauley, 2015) .It occupied 17% of cultivated land (FAOSTAT, 2015) and 21% in East Africa (Ndlovu, 2013). In Rwanda, maize is one of the six priority crops (wheat, rice, banana, cassava, potatoes) which the government of Rwanda has been selected for the land consolidation and crop intensification program (CIP) in 2007 to transform subsistence agriculture into intensive agriculture (MINAGRI, 2013). Maize is the first important cereal crop in Rwanda that occupies 16.8% of arable land followed by sorghum (2,4%), rice (1.9%) and lastly wheat (0.2%) (NISR, 2017). However, maize is very sensitive to drought at different growth stages from germination to maturity (Muhammad *et al.*, 2015). As a matter of fact, the

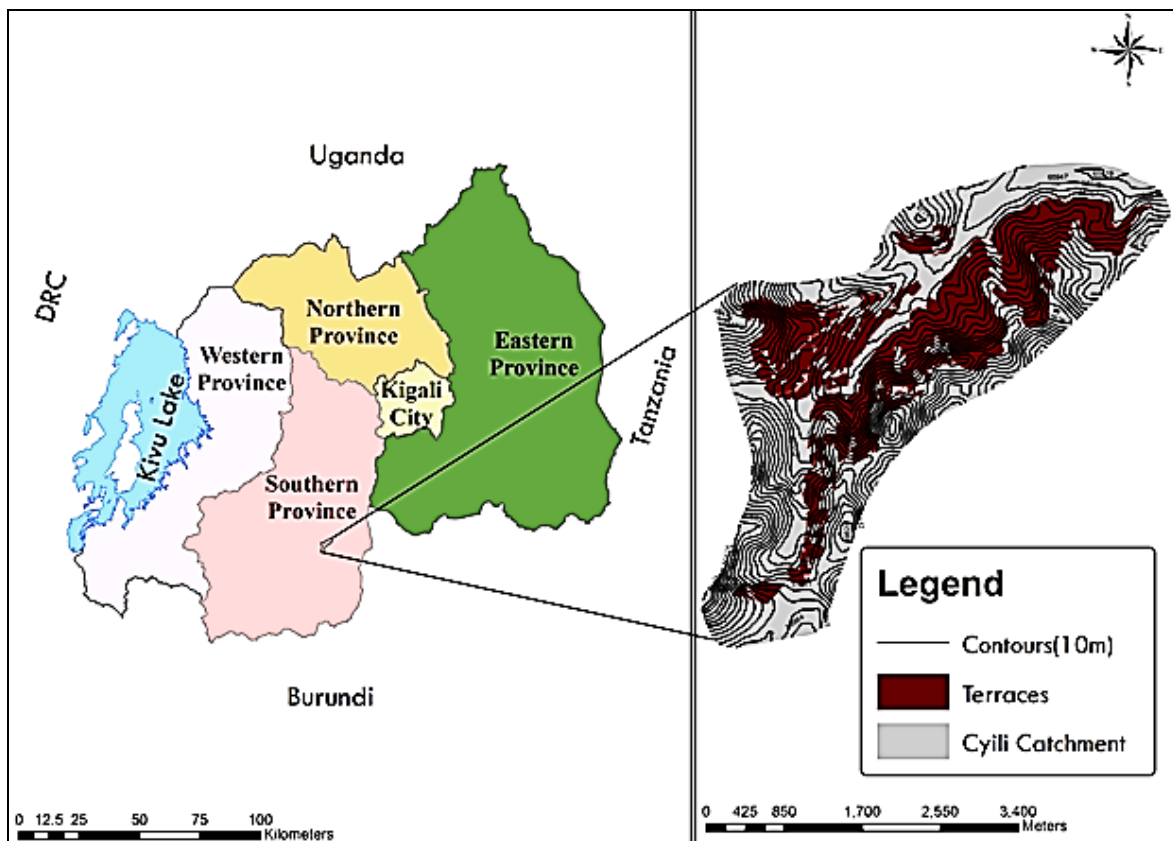
maize germination rate is reduced under drought stress conditions due to low water absorption and metabolic enzymatic processes (Gharoobi *et al.*, 2012). During the development growth stages of maize, drought affect cell division and cell proliferation (Muhammad *et al.*, 2015), while in the reproductive stage drought affecting tassel, embryo, endosperm development, ear, pollination, fertilization grain filling resulting in loss of crop yield (DuPlessis, 2003).since most of sub Saharan Africa maize production is based on rainfed systems (Gebrehiwot and Gebrewahid, 2016), there is a need to find out alternative soil moisture conservation strategies to mitigate drought negative effects. In this regards, mulching, tied ridges, terracing, bunding, rain water harvesting and supplementary irrigation method are some of the methods with high potential soil water conservation.

Mulching is a common soil conservation method that farmers use to cover the soil surface for the purpose of retaining moisture in the soil, reduce soil temperature to contain evaporation and to improve soil fertility or organic matter content (Li and Gong, 2002; Gicheru, 1994). Supplementary irrigation adds water to the plants in the critical time to improve soil moisture (Oweis *et al.*, 1999) while contour ridges is regarded as water harvesting methods in semi-arid regions. It transforms the land into small furrows called tied ridges and is very useful to stabilize yield (SUSTAINET, 2010; Bargar *et al.*, 1999). The objective of this study was to identify the best water conservation method that can give maximum maize grain yield in hotter and dryer regions. The findings of this study will contribute to mitigate the effect of climate change especially increased temperature and prolonged drought and hence enhance maize productivity in the drought prone regions of Rwanda.

## 5.2. Materials and Methods

### 5.2.1. Study area

The study was conducted in Cyili sub-catchment (02°34'32.52"S and 29°51'52.23"E with elevations varying between 1467 to 1604 masl). Cyili sub-catchment is shared by two districts of Southern Province of Rwanda, Huye and Gisagara. The area is characterized by highly steep slopes which are conserved with bench terraces installed by the Government of Rwanda in 2013. Figure 5.1 shows the location of the study area in the administrative map of Rwanda. The catchment has the total area of 4.30 km<sup>2</sup> and it has a total number of 1,114 farmers.



**Figure 5 1: Map of Cyili sub-catchment location**

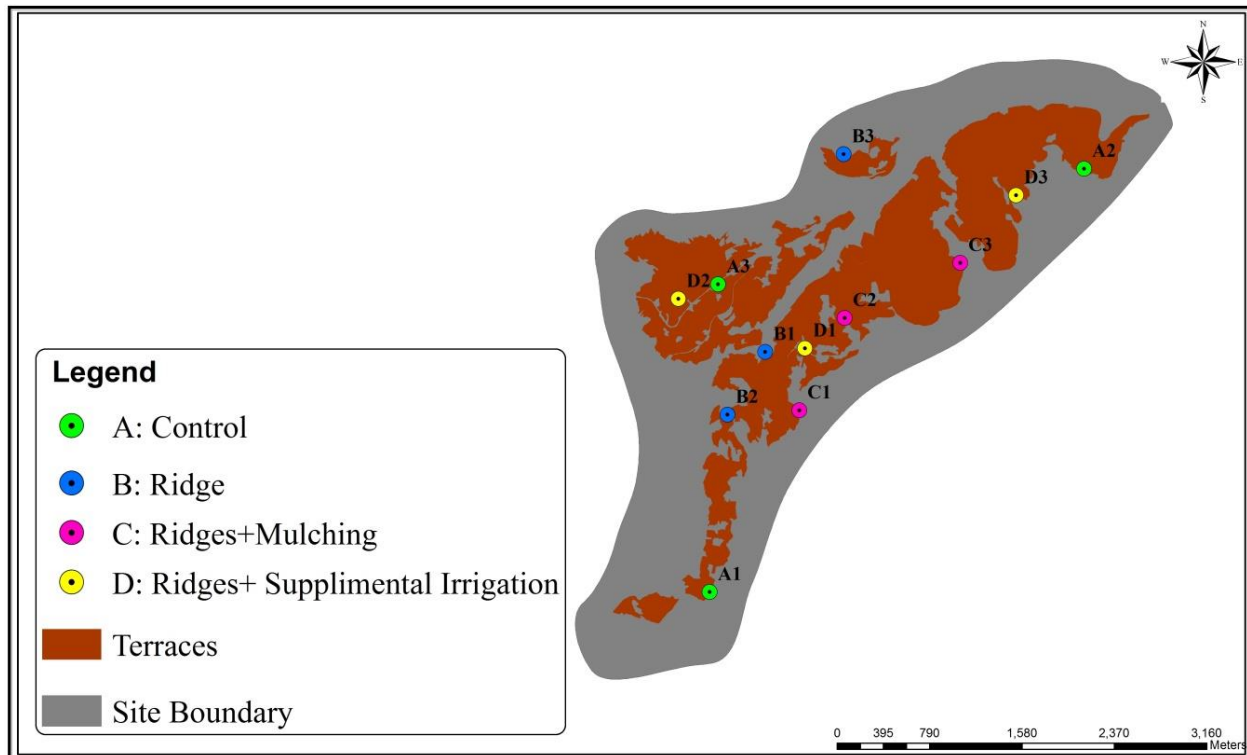
The catchment has a wide range soil type characteristics and climate that are similar to that of the central plateau (middle altitude) of the country. The dominant soil types are Luvisols, Alisols,



and Cambisols (FAO, 2003). Based on topography and climate of country Cyili sub-catchment is classified in sub-humid and fall under Mayaga agro-ecological zone (IX) with extreme spatial and temporal rainfall distribution (Verdoodt and Van Ranst, 2006). The catchment receives annual rainfall of about 1,141 mm at Rubona station. Rainfall is bimodal, with long rain period occurring in March to May and the short rains in mid-September to mid-December every year. Mean annual temperature range from 14.2<sup>0</sup>C to 24.8<sup>0</sup>C (MINAGRI, 2010). The land is suitable for cereal crops such as maize (*zea mays*), rice (*Oryza sativa*), sorghum (*Sorghum bicolor*), root and tuber crops such as cassava (*Manihot esculenta*), sweet potato (*Ipomoea batatas*) and yam (*Dioscorea alata*), grain legumes such as groundnuts (*Arachis hypogaea*) and soybean (*Glycine max*), and fruit trees such as avocados (*Persea americana*) and coffee (*coffea arabica*) (MINAGRI, 2010).

### **5.2.2. Experimental design**

The study field activities were started from the 15<sup>th</sup> August to 10<sup>th</sup> September 2016 with land preparation, involving ploughing, harrowing. The four treatments consisting of 4 different soil water conservation methods: A: rainfed (control or check); B: ridges + mulching; C: contour ridges and D: ridges + supplemental irrigation was installed. The experiment was arranged in completely randomized design (CRD) and each treatment was replicated three times as shown in Figure 5.2.



**Figure 5 2: Trial structure and treatments location in Cyili sub-catchment**

Each experimental plot was 3 m wide and 6 m long with a population density of 47,619 plant/ha at a spacing of 70 cm x 30 cm within and between rows. Two seeds of maize seeds (PAN53) were planted per hole. PAN53 is one of best maize hybrid varieties in Rwanda. That has high yield potential and adapted to a wide range of agro-ecological zones of Rwanda (Ngaboyisonga *et al.*, 2016). This maize hybrid originated from South Africa and was kindly availed to the Rwanda Agriculture Board (RAB), maize research Programme. Organic and inorganic fertilizers were applied at the rate of 10 ton per ha (farm yard manure); 100 kg per ha of DAP (Diammonium phosphate) and 50 kg per ha of Urea as recommended by MINAGRI (2009) in all the plots and weeding was done after 6 six weeks.

### 5.2.3. Treatment establishment and trial maintenance

#### *a. Supplementary irrigation through drip irrigation*

The drip irrigation used in this study is a drum drip kit. The main components of drum kit system are a drum, a filter, connectors and a drip time. The drum containing irrigation water was set up at 1 m above ground on a wooden stand placed at the highest point of the plot. The runoff used for irrigations was derived from the water ways of radical terraces into a constructed water pond. Water was filtered to remove sediments before placing it in the drum to prevent clogging of the drip emitters. Water flow to the experimental plots was by gravity as illustrated on Figure 5.3



**Figure 5.3: Photographs showing lined water pan for harvesting run-off water (a) and Maize plot under drip irrigation with the harvested run-off water (b)**

### *b. Contour ridges*

Contour ridges method was used to increase surface run-off storage near the cropped area, in contrast to the flat planting. The construction of contour ridges was manually constructed after ploughing using hoe and tape measure. The size of ridges was 60 cm wide and 20cm of high. The spacing between ridges was 20 cm and furrow canal was serving as rainwater harvesting zone shown in Figure 5.4.



**Figure 5 4: Maize under contour ridge and furrow canals plot**

### *c. Mulching*

The organic mulching is a commonly conservation method used in semi-arid to improve soil fertility and maintain soil moisture. Vetiver grass (*Vetiveria nigriflora*) was used as mulch as shown on figure 5.5. The organic mulch was applied after seed sowing.





**Figure 5 5: Maize on ridges and vetiver grass mulching**

*d. Rainfed control*

The rainfed control treatment maize seed was sowed on flat land without ridge after second ploughing similar to the actual local farmers' done.

#### **5.2.4. Data collection**

During this study, several measurements were performed to assess the effect of the different soil moisture conservation method on soil properties, crop yield and associated yield components.

##### **5.2.4.1. Soil physical properties measurements**

The soil physical properties including soil texture, bulk density and available water content were assessed before the start of the experiment (explained in chapter 3 and 4)

##### **5.2.4.2 Growth and yield parameters**

Growth and yield data were collected using growth parameters including germination rate, plant height, and number of leaves per plant. Ten plants were selected randomly from each plot. The

germination of sowed seeds was determined by daily examination from 7 days after sowing, Plant height was measured with a tape measure tool from the base of the plant to the height of the first tassel branch. Plant height, number of leaves was computed for seven days interval from first week to 10weeks after snowing. Yield parameters were also assessed after harvesting. These include cob length, cob diameter, number of grains per cob, weights of hundred grains, grain yield per plant and grain yield per ha for each treatment. The grain yields were expressed at 12.5% moisture content.

#### **5.2.6. Data analysis**

Statistical analyses were performed to test the influence of water conservation methods (mulching, ridge, irrigation and rainfed as a check) on maize grain yields and yield components, using one-way analysis of variance (ANOVA) in completely randomized design (CRD). The ANOVA was computed according to REML procedure using Genstat 14<sup>th</sup> edition to fit the following model as described by (O'Neill, 2010) :

$$Y_{ij} = \mu + t_i + \varepsilon_{ij}$$

Where  $Y_{ij}$  = observed yield of plant  $j$  in treatment  $i$ ,  $\mu$  = Overall mean,  $t_i$  = the  $i^{\text{th}}$  effect due to the treatment,  $\varepsilon_{ij}$  = unobserved error or term error.

Mean squares were estimated and significant differences were declared using 1 and 5%. Mean comparisons were made using Duncan's multiple range tests with  $p < 0.05$ . Pearson's correlation coefficient test was carried out to assess the relationship between yield parameters (germination, plant height, number of leaves, cob length and diameter, weight of grain per cob, weight of hundreds grains and grain yield per plant) and grain yields under water conservation methods using Minitab software version 17.

### 5.3. Results and discussions

#### 5.3.1. Effect of water conservation methods on maize growth

Soil moisture content variability effect of crop growth. In this regards the effect of different soil moisture content obtained from various water conservation methods on maize growth parameters is illustrated in Table 5.1.

**Table 5 1: Mean performance of maize growth parameters under different water conservation methods**

Water conservation methods	Germination rate (%)	Plant height for 10 weeks (cm)	Leaf number for 10 weeks	Cob number/plant
Rainfed	79.00 <sup>a</sup>	150.7 <sup>c</sup>	14.05 <sup>c</sup>	83.01 <sup>a</sup>
Ridges	77.67 <sup>a</sup>	158.02 <sup>c</sup>	16.01 <sup>b</sup>	83.03 <sup>a</sup>
Ridges + Mulching	78.33 <sup>a</sup>	175.03 <sup>b</sup>	16.02 <sup>b</sup>	80.67 <sup>a</sup>
Ridges + Irrigation	79.33 <sup>a</sup>	240.7 <sup>a</sup>	18.04 <sup>a</sup>	91.01 <sup>b</sup>
Mean	78.58	181.1	16.1	81.67
LSD (0.05)	0.46	13.40	0.54	3.65
CV%	2.8	3.9	1.8	2.2
P-value	>0.805 <sup>ns</sup>	<0.001 <sup>**</sup>	<0.001 <sup>**</sup>	0.014 <sup>**</sup>

Means having the same letter(s) are not significantly different according to DMRT at 5%; CV: Coefficient of variation, LSD: Least significance difference, \*&\*\* : level of significance at  $P < 0.05$  or  $P < 0.001$ ); ns: non-significant

The results analysis of variance for mean squares revealed that the maize growth parameters were significantly increased ( $P < 0.001$ ) by the studied water conservation methods except for germination rate which was not significant ( $p > 0.05$ ). The data show that the plant height was increased significantly ( $p < 0.001$ ) in supplementary irrigation treatment (240.7 cm), followed by mulching treatment (175.03 cm) when compared to the control (150cm). There was no significant difference between contour ridge (158 cm) and rainfed treatment (150 cm). Likewise,

supplementary irrigation increased highly significance difference ( $p < 0.001$ ) for leaf number and cob number per plant followed by mulching and ridge and most dwarf was obtained by control plots (rainfed). The present results are in accordance with the findings of Karasu *et al.* (2015); Mostafa and Derbala, (2015), who reported that the availability of water in the treatments (irrigation, mulching) increased significantly maize yield components and yield. Water is very important for crop development from germination to maturity, deficiency of water decrease cell division and cell proliferation which generate lower grain yield and fail crop (Muhammad *et al.*, 2015; DuPlessis, 2003). Findings from present study showed that the germination was not significantly affected by water conservation method probably because rainfall was adequate during sowing. In general under water stress caused poor germination which is decline an agreement with previous studies reported by Karasu *et al.* (2015) and Çakir (2004).

### **5.3.2. The effect of the performance of maize yield components under various soil water conservation methods**

The data in Table 5.2 show that the effect of various water conservation methods was significant ( $p < 0.001$ ) on all yield components (cob length and diameter, number of cob per plant). Result combined in Table 5.2 show that the supplementary irrigation treatment was highly significance difference increased cob diameter (16.7cm), cob length (22.74cm) as well as number of cob per plant (91.01), followed by mulching and contour ridge.



**Table 5 2: Mean performance of maize yield parameters under soil water conservation methods**

Water conservation methods	Cob Diameter (cm)	Cob length(cm)	Cob number/plant
Rainfed (control)	15.71 <sup>bc</sup>	14.41 <sup>d</sup>	83.01 <sup>a</sup>
Ridges	14.98 <sup>c</sup>	17.47 <sup>c</sup>	83.03 <sup>a</sup>
Ridges + Mulching	16.03 <sup>ab</sup>	21.03 <sup>b</sup>	80.67 <sup>a</sup>
Ridges + Irrigation	16.7 <sup>a</sup>	22.74 <sup>a</sup>	91.01 <sup>b</sup>
Mean	15.85	18.9	81.67
LSD (0.05)	0.84	1.59	3.65
CV (%)	2.7	4.2	2.2
P-value	<0.014 <sup>*</sup>	<0.001 <sup>**</sup>	<0.014 <sup>*</sup>

Means have the same letter(s) are not significantly different according to DMRT at 5%, CV: Coefficient of variation, LSD: Least significance difference, \*&\*\* : level of significance at P < 0.05 or P<0.001

Soil moisture content is reported to control plant phenological, physiological and morphological (Khan et al., 2001). Once decrease the number of grain per plant; yield per unit area and number of corn-cob per plant are decrease (Mansouri et al., 2010; Pandey et al., 2000), similar to current study the most dwarf of corn-cob diameter; length and, corn-cob number per plant, were found in rainfed treatment because of deficit water. The reason for observed results is that supplementary irrigation treatment had more water than mulching and mulching treatment save water than contour ridges while contour ridges treatment improve soil moisture and store water than flat planting (rainfed) these was an agreement by previous studies (Muhammad *et al.*, 2015; Khodarahmpour, 2011; Çakir, 2004 and Khan *et al.*, 2001). This implies that the grain yield and yield components were increased significantly according to the availability of water in the

treatments. The current results agree with the findings of Qin *et al.*(2015) and Qi *et al.*(2016) who reported supplementary irrigation had significant increase on grain yield and yield components.

### 5.3.3. The maize grain yield under different soil water conservation methods

The data on grain yield data, number of grain per cob, weight of grain per cob, 100grain per cob, grain yield per plant and yield per plant) given in Table 5.3 show that grain yield and yield components were increased significantly ( $p < 0.001$ ) by water conservation methods and irrigation when compared to the control (Rainfed).

**Table 5 3: Mean performance of grain yield data under various water conservation methods**

Water conservation methods	Number of Grain/cob	Weight grain/Cob(g)	weight 100grain	Grain yield/plant(g)	Yield kg/ha
Rainfed (control)	288 <sup>d</sup>	99.2 <sup>c</sup>	35.09b	101.7 <sup>c</sup>	4755 <sup>c</sup>
Ridges	368 <sup>c</sup>	122.2 <sup>c</sup>	30.40c	127.3 <sup>c</sup>	5937 <sup>c</sup>
Ridges + Mulching	531.3 <sup>b</sup>	195.7 <sup>b</sup>	38.42ab	201.5 <sup>b</sup>	8089 <sup>b</sup>
Ridges + Irrigation	595 <sup>a</sup>	241.6 <sup>a</sup>	40.44a	254.9 <sup>a</sup>	11982 <sup>a</sup>
Mean	445.6	164.7	36.1	171.3	7690.75
LSD (0.05)	48.08	38.88	4.13	40.93	1795.9
CV (%)	5.4	11.8	5.7	12	11.7
LS (P value)	<0.001 <sup>**</sup>	<0.001 <sup>**</sup>	<0.001 <sup>**</sup>	<0.001 <sup>**</sup>	<0.001 <sup>**</sup>

Means having the same letter(s) are not significantly different according to DMRT at 5%; CV: Coefficient of variation, LSD: Least significance difference, \*&\*\* : level of significance at  $P < 0.05$  or  $P < 0.001$ ); ns: non-significant

The grain yield obtained in supplementary irrigation treatment (11,982 kg/ha), mulching (8089 kg/ha) and contour ridge (5937 kg/ha) were significantly different. Yield between contour ridge (5937 kg/ha) and rainfed (4755 kg/ha) were not significantly different. The number of grain per cob, weight of grain per cob, 100grain per cob, grain yield per plant were affected according to the availability moisture content under various water conservation methods. Mulching treatment was the second after supplementary irrigation in grain yield production and yield component probably due to the fact that mulching resulted in addition improvement soil nutrition through incorporation of soil organic matter after mulch decomposition. Babalola *et al.*(2007) also reported that the mulching breaks impact of raindrops on the soil surface (soil erosion), encourages water infiltration and is organ-mineral fertilizer on soil. The significantly higher yield in the contour ridge than rainfed (planting on flat land) may have resulted from the ridge capacity to retain surface runoff near the cropped area, reduced risk of erosion and increased water holding capacity of the soil. It was an agreement with reports by Hailemariam (2016) who reported that the tie ridge increase sorghum yield above 34.5% compare to the rainfed agriculture. Rainfed treatment presented low yield and yield components compare to the other water conservation methods may attributed to the low ability to retain the soil moisture.

This result is also in conformity with the findings of Solomon (2015) and Yoseph (2014) who reported that maize grain yield and growth yield parameters were significantly affected by moisture conservation practices. Similar findings by Tekle (2014b) and Ramachandrapa *et al.*(2012) showed higher yield and yield components of pearl millet and rabi sorghum in moisture conservation treatment that was attributed to available soil moisture. The present study revealed that grain yield under supplementary irrigation treatment was slightly double than

rainfed treatment. These results similar to that of Karasu *et al.* (2015 who reported grain yield under supplementary irrigation treatment (18,268 kg ha<sup>-1</sup>) was more than double than that obtained in the rainfed treatment (7,123 kg ha<sup>-1</sup>). Likewise the findings by Rosegrant *et al.* (2002) who reported in the development countries there is significance different the grain yield between rainfed (1.5t/ha) and irrigation agriculture (3.1t/ha). This suggests that the supplementary irrigation and mulching are the best agriculture practice to increase the food production not only in Rwanda but in sub-Saharan Africa. Many researchers in the world were confirmed and recommended supplementary irrigation has improved crop yields Li and Gong, (2002) for the Northwest of China; Karasu *et al.*(2015) in Bursa Marmara region, Turkey and Doto *et al.* (2015) in Burkina Faso country.

#### **5.2.4. Relationship between maize grain yield and yield components**

Relationship between grain yield and yield components were assessed using Pearson coefficients of correlation is presented in Table 5.3. Revealed that the maize grain yield and yield components were positive and statistically significant ( $p < 0.001$ ) under various water conservation methods. The highest correlation coefficient was observed between grain yield per plant and grain yield per unit area ( $r = 0.987^{**}$ ) followed by weight of grain per cob and yield per unit area ( $r = 0.987^{**}$ ) while the least correlation was obtained between the cob number per plant and number of grain per cob ( $r = 0.422^*$ ). The current result compare with those of Karasu *et al.* (2015), Kumar *et al.* (2014) and Ilker (2011) who reported that their were significant correlations between grain yield and yield components.

**Table 5 4: Pearson's correlation coefficient matrix between maize grain yield and yield components**

	P H	N L	N C	D C	C L	N G C	W G C	G Y P
P H								
N L	0.890 <sup>ns</sup>							
N C	0.651 <sup>*</sup>	0.539 <sup>*</sup>						
D C	0.725 <sup>*</sup>	0.523 <sup>*</sup>	0.638 <sup>*</sup>					
C L	0.801 <sup>**</sup>	0.899 <sup>**</sup>	0.535 <sup>*</sup>	0.641 <sup>*</sup>				
N G C	0.822 <sup>**</sup>	0.883 <sup>**</sup>	0.422 <sup>*</sup>	0.672 <sup>*</sup>	0.968 <sup>**</sup>			
W G C	0.859 <sup>**</sup>	0.850 <sup>**</sup>	0.453 <sup>*</sup>	0.749 <sup>*</sup>	0.943 <sup>**</sup>	0.977 <sup>**</sup>		
G Y P	0.872 <sup>ns</sup>	0.858 <sup>ns</sup>	0.465 <sup>ns</sup>	0.746 <sup>ns</sup>	0.941 <sup>ns</sup>	0.971 <sup>ns</sup>	0.999 <sup>ns</sup>	
G Y	0.982 <sup>**</sup>	0.929 <sup>**</sup>	0.831 <sup>*</sup>	0.931 <sup>*</sup>	0.942 <sup>**</sup>	0.972 <sup>**</sup>	0.978 <sup>**</sup>	0.987 <sup>**</sup>

P.H: Plant height (cm); N L: Number of leaf; N C: Cob number, D C: Cob diameter (cm); C.L: Cob length (cm); N G C: Number of grain/Cob; W G C: Weight of grain/Cob (g), GYP: Grain yield/plant (g), G Y: grain yield/hectare \*, \*\*: F-test significant at  $p \leq 0.05$  or  $0.001$ ; ns: not significant

The present study found significant correlations ( $p > 0.05$ ) between maize grain yield and plant height as well as grain yield per plant (Table 5.3), this may attributed by the presence of available water during the growing season and plant density (70x30cm). This is in agreement with reports by Muhammad *et al.*(2015) and Sangoi and Salvador (1985) who concluded that the deficit water or drought and higher plant population decrease plant height, grain yield, biomass production. This is in contrasts with the reports of Karasu *et al.* (2015) and Amini *et al.* (2013) who observed higher correlation between plant height and yield component as well as grain yield per plant and yield components.

#### **5.4. Conclusions and recommendations**

Present study concluded that different agricultural water conservation methods (mulching, ridges and supplementary irrigation) saved limited water and improved grain yield per hectare in Cyili sub-catchment. Through rainwater harvesting from surface runoff, supplemental irrigation treatment was significantly produced higher grain yield slightly double compare to rainfed grain yield followed by mulching and contour ridge. This suggests that the growers or famers must considered the cost of supplementary irrigation and market preferences before apply to the large scale. Grain yield and all yield components were positively correlated and significant under water conservation methods except germination rate was not significant due to the presence of available water in the period of sowing. Ridge covered by organic mulching and supplementary irrigation could be an option to mitigate dry spells and to improve livelihoods farmers' income generation in the area of row rainfall. However, regarding maize grain yield can be considered as a thoughtful potential to develop as far as farming systems. This study also revealed useful information to be taken into consideration in the development of high yielding and water conservation management in East Africa as far as in sub-sahara Africa.

## **CHAPTER SIX:**

### **GENERAL CONCLUSION AND RECOMMENDATIONS**

#### **6.0 General Conclusions**

##### **6.1 Establishment, utilization, management and benefits of supplementary irrigation**

Understanding soil moisture variation is very important to the farmers in predicting irrigation and available water requirement for plant growth. The aim of this study was to explore the potential of supplementary irrigation using harvested runoff with a particular focus on Cyili sub-catchment, in Southern Province of Rwanda. The research aimed at understanding soil water content and water required to improve maize yield determining soil moisture variation and supplementary irrigation water requirement, quantifying surface runoff generated in Cyili sub-catchment and the best soil water conservation practices required to improve crop production in the catchment.

The findings in this study revealed that the average soil moisture in the subsoil was significantly higher than in topsoil. Mainly responsible was clay soil accumulated in the subsoil, high evaporation of soil water on the surface and the vegetation cover in the top than in subsoil. Soil moisture variation was high in the upper than in the lower part of the sub-catchment, heterogeneity of soil type; land use and agricultural activities in the lower part of the sub-catchment are the facts.

Proper irrigation scheduling supports the farmers to apply water more efficiently taking into account crop evaporation and rainfall. This study observed that sowing on time affect the amount of water requirement and the length of the crop cycle. Cyili sub-catchment assessment in terms

of topography is necessary to understand the morphological and hydrological development of the catchments. The findings from this study revealed that the Cyili sub-catchment characterized by high slope and high elevation which was produce irregular network for hydrological active process. Furthermore, the catchment has been the poor rainfall distribution and more rainwater was loss due to the poor management. Cyili sub-catchment has higher potential volume of runoff to stabilize the deficit water; farmers must adopt the rainwater harvesting to supplemental the crop in the period of dry spell.

Moreover, this study found that the water conservation methods positively and significantly ( $P < 0.001$ ) influencing morphometric parameters for maize growth and grain yield except germination rate was not significant ( $p > 0.05$ ). Findings revealed that supplementary irrigation and mulching have increased significantly yield components (height, number of leaves, cob length and diameter, number of grain/plant, weight of grain/plant) of maize compare to the contour ridge and rainfed method. Supplementary irrigation and contour ridge combined mulching may a potential option to generate higher yield and water use efficient in drought prone agro-ecological zone like a Cyili sub-catchment in Rwanda.

## **6.2. Recommendations**

This study has concluded that runoff generated in Cyili sub-catchments has potential to increase yield slightly double compare to actual agricultural practice (rainfed). However, integrated watershed management of Cyili sub-catchment is critical to improve water resources management in the quality and profitability to fight against the food insecurity and poverty. Some of the recommended areas of future research are:



- a) The need a solution of unemployment of Cyili farmers in Dry season C (June to September) in that period land is left fallow. Further research could study if the volume of runoff generated in Cyili sub-catchment for long rainy season B (March to May) can irrigate the crop in dry season.
- b) The continuous adoption and alteration burning of crop residues, eliminating ridges, excessive tillage in Cyili sub-catchment has been seen reduce soil water holding capacity and soil biology activities. There is need a research focus on the consequence of burning crop residues.
- c) Water-harvesting and supplementary irrigation require investments in term of finance. A detailed cost-benefit analysis (CBA) is needed to inform the farmers income and return period for this technology
- d) Lower agroforestry species in Cyili sub-catchment generate high soil evaporation, more moisture loss on soil surface and limited rainfall. In this regard, a need a study focus on the adopted new agroforestry species resist to the climate of that area. This will improve soil fertility and productivity of land.

### **6.2.2. Implications for Research**

In a bid to maintain water resources and to increase yield production in Cyili sub-catchment farmers should adopt rain water harvesting and water conservation methods especially ridging combine the mulching. In addition, the following recommendations need attention:

- a) The farmers in Cyili sub-catchment should plant on date of rainfall for minimise rainfall water lost in the late period of sowing (September to October) and apply supplementary irrigation in 10 days at development stage,

- b) The farmers in the low elevation of sub-catchment must adopt furrow ridge for mitigating the flooding of water from the upper of sub-catchment and cleaning the waterways, hydraulic structures was constructed by MINAGRI,
- c) The study of runoff generated in the catchment requires more accuracy and information data on meteorology and geographic sources. This suggests that Government of Rwanda should increase the number of meteorology station and qualified materials as well as technicians to facilitate the future research for study other different catchment in Rwanda,
- d) Extensionist and farmers should use the findings from this study for sustainable water resources and agriculture development.

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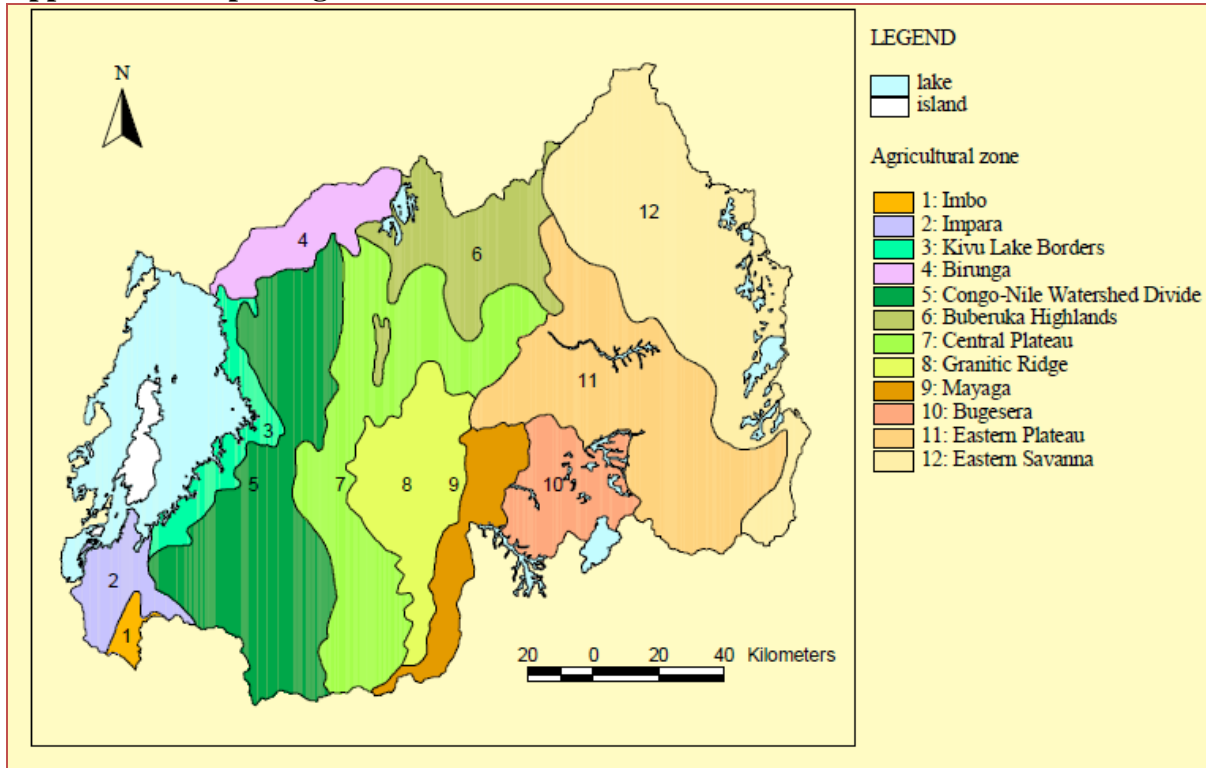


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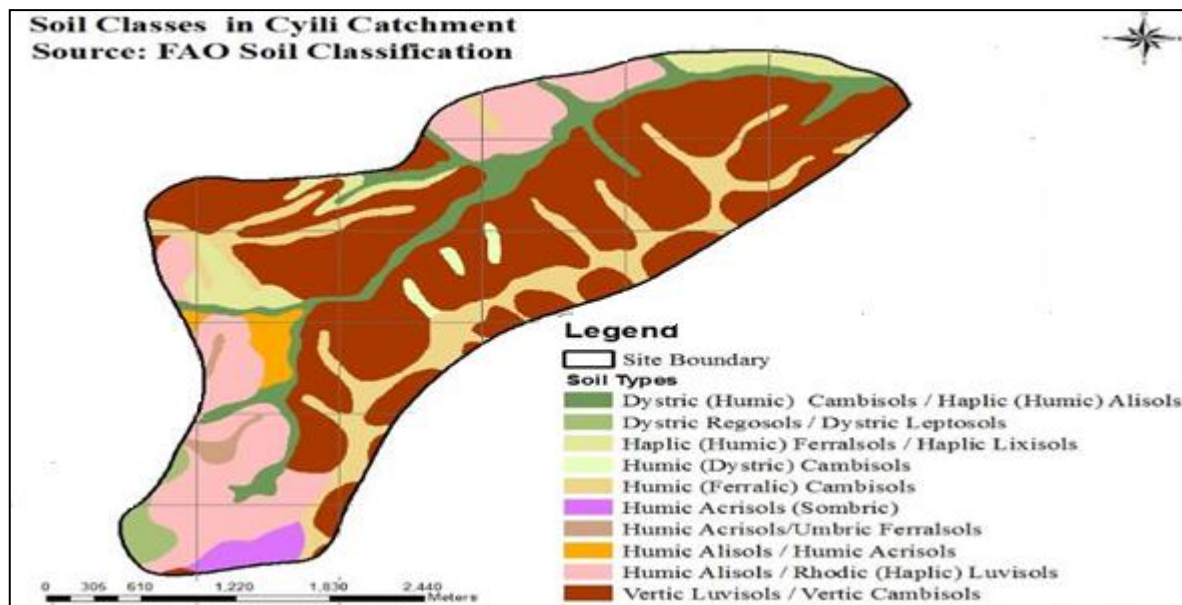
## APPENDICES

### Appendix 1: Map of Agricultural zones in Rwanda

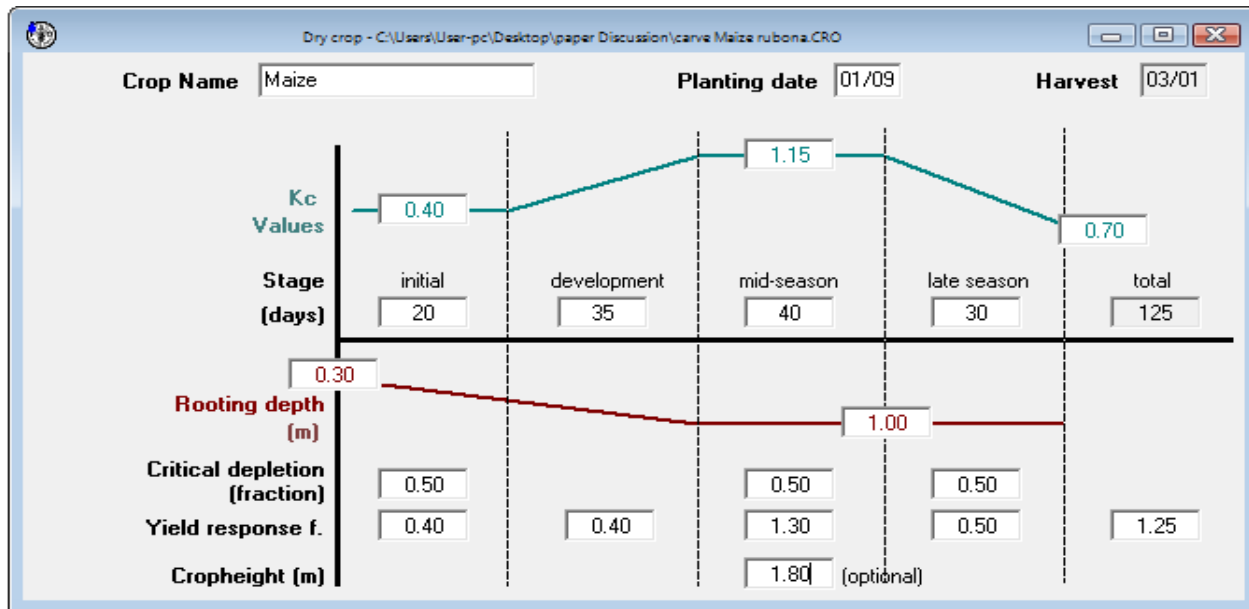


Source: Verdoodt and Ranst.(2003).

### Appendix 2: Soil classification map of Cyili sub-catchment



### Appendix 3: Crop coefficient for Maize crop



#### Appendix 4: Initial soil moisture depletion

The screenshot shows a software window titled "Soil - untitled" with the following data:

- Soil name:** Sand Clay loam
- General soil data:**
  - Total available soil moisture (FC - WP):** 40.2 mm/meter
  - Maximum rain infiltration rate:** 25 mm/day
  - Maximum rooting depth:** 100 centimeters
  - Initial soil moisture depletion (as % TAM):** 50 %
  - Initial available soil moisture:** 20.1 mm/meter

## Appendix 5: Soil Texture and water content for all treatments.

Treatment	Depth(Cm)	Soil Texture	W C at FC	BD(mg/m <sup>3</sup> )	PAWC	x	y	Elevation(m)
Rainfed (A1)	0-30	Silt Loam	5.72	1.96	3.37	E00476562	N 04724547	1541
	30-60	Loamy Sandy Clay	8.14	2.01	10.2			
Ridge(B2)	0-30	Loam Sandy Clay	2.64	1.99	1.57	E00476714	N04726060	1486
	30-60	Loam	2.47	2.01	2.97			
Mulching(C1)	0-30	Sandy Clay	5.08	1.92	2.92	E00477328	N04726097	1528
	30-60	Silt Sandy Clay	4.61	1.72	4.75			
Irrigation(D1)	0-30	Loam Sandy Clay	2.66	2.13	1.7	E00477376	N04726628	1467
	30-60	Loam	2.94	2.1	3.71			
Ridge(B1)	0-30	Sandy clay Sandy Clay	4.89	2.01	2.94	E00477037	N04726597	1485
	30-60	Loam Sandy Clay	4.15	2.31	5.75			
Rainfed(A3)	0-30	Loam	2.43	1.99	1.45	E00476635	N04727174	1558
	30-60	Silt Sandy Clay	2.77	2.22	3.69			
Irrigation(D2)	0-30	Loam	3.11	2.03	1.89	E00476295	N04727050	1604
	30-60	Silt	3.56	2.05	4.38			
Ridge(B3)	0-30	Silt Sandy Clay	2.44	2.06	1.51	E00477708	NO4728283	1514
	30-60	Loam	7.35	2.03	8.94			
Mulching(C3)	0-30	Clay loam	2.62	2.14	1.69	E00478705	N04727357	1561
	30-60	Silt Sandy Clay	4.52	2.47	6.71			
Irrigation(D3)	0-30	Loam	6.2	1.96	3.65	E00479181	N04727933	1580
	30-60	Clay	3.26	2.04	3.98			
Rainfed(A2)	0-30	Clay	1.35	2.14	3.11	E00479762	N04728159	1506
	30-60	Silt	4.94	2.1	1.73			
Mulching(C2)	0-30	Silt Loam	3.39	2.02	2.05	E00477716	N04726887	1554
	30-60	Silt	9.44	2.08	11.75			

### Appendix 6: Mean square estimates for grain yield and yield components under different soil water conservation methods

Source of variation	df	Germination rate	Plant height	Number of leaves	Cob/plant	Cob Diameter (cm)	Cob length	No of Grain/	Weight of grain/100	weight	Grain yield/	Yield kg/ha
Replication	2	0.083	50.67	0.083	0.333	0.1916	0.1658	169.1	72.3	8.863	138.4	678476
Water conservation methods	3	1.639 (>0.805)	5045.19 (<0.001)	8.083 (<0.001)	7.333 (<0.014)	1.5315 (<0.014)	41.4524 (<0.001)	60530.1 (<0.001)	12966.5 (<0.001)	57.712 (<0.001)	14684.3 (<0.001)	30267697 (<0.001)
Residual	6	4.972	50.67	0.083	3.333	0.1778	0.631	579.1	378.8	4.278	419.6	807992
Total	11	3.174	1412.81	2.265	3.878	0.5495	11.679	16854.81	3756.08	19.684	4258.87	8757229.18
c.v (%)		2.8	3.9	1.8	2.2	0.42	0.79	24.06	19.46	2.07	20.49	898.9
S.E		2.23	7.12	0.26	1.83	2.7	4.2	5.4	11.8	5.7	12	11.7

df= degree of freedom, SE=Standard error, CV: Coefficient of variation, numbers between blanket are P values.