

**CLIMBING AND BUSH BEANS' CULTIVATION EFFECTS ON RUNOFF,  
SOIL PROPERTIES AND SOIL AND NUTRIENT LOSSES IN BUFUNDI SUB  
CATCHMENT, UGANDA**

By

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**DECLARATION**

This thesis is my original work and has not been presented for a degree or any other award in any other university.

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## **DEDICATION**

This work is dedicated first and foremost to my Late Father and Mother Patrick Osangi Gabiri and Mrs. Osangi Topista Kilego; my academic parents Prof Tenywa Moses, and Prof. Obando Joy, my fiance Natuhwera Malson; my guardian Mukama Stephen, my brothers Dr. Tukei Robert, Miyo Laban, Okolimong Herbert, Ekaba Lambert and my sisters Sabano Leah and Sagati Sylvia.

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**LIST OF ACRONYMS AND ABBREVIATIONS**

<b>ANOVA</b>	Analysis of Variance
<b>CRBD</b>	Complete Random Block Design
<b>K</b>	Potassium
<b>LSD</b>	Least Significance Difference
<b>MWD</b>	Mean Weight Diameter
<b>N</b>	Nitrogen
<b>P</b>	Phosphorus
<b>SOC</b>	Soil Organic Carbon
<b>SSA</b>	Sub-Saharan Africa
<b>SW</b>	South Western
<b>SWC</b>	Soil and Water Conservation
<b>NGOs</b>	Non- Government Organizations

## ABSTRACT

Climbing beans were developed by International Centre for Tropical Agriculture (CIAT) and are heavily being promoted over bush beans in humid highlands of South Western Uganda; characterized by steep degrading hill-slopes. Climbing beans yield two to four times more than bush beans and are characterized with heavy vegetation cover and longer maturity period of 200 days over bush beans. These two types of beans are the major legume cover crops heavily cultivated at the middle landscape position in Bufundi catchment. The catchment is heavily experiencing limited arable land due to declining soil fertility attributed to increased soil erosion. Several studies have been conducted on these two types of beans on various thematic areas however; the empirical contribution of each of the two types of beans in controlling runoff, soil and nutrient losses down the catchment is not clear and documented. Therefore, this study was carried out to assess the effects of climbing and bush beans' cultivation on runoff, soil and nutrient losses and soil properties in Bufundi catchment, Southwestern Uganda. Specific objectives included determining runoff; examining soil and nutrient losses as well as evaluating the effect of these bean types on soil properties. The experiment adopted runoff approach and conducted at the middle landscape position at three farmers' terraced sites with slope range of 23 -29 % which were representative of those terraces commonly found in the study area. A total of 18 runoff trap plots measuring 2 x 9 m were established. Climbing and bush beans were planted and replicated thrice at each farmer's site. Half the number of plots was planted with climbing beans and the other half with bush beans for two rainfall seasons in 2012. Before planting and after harvest, a total of twelve composite soil samples were taken at depths of 0-15 cm and 15- 30 cm within the runoff plots and characterized in the laboratory for soil pH, Soil Organic Carbon, total nitrogen, available phosphorus and exchangeable potassium and soil structure. Runoff was measured using a measuring cylinder after every rain event and the measured volume poured in clean bottles for soil and nutrient losses analysis. Precipitation received per storm event was recorded using a non-recording rain gauge. Soil and nutrients (Total nitrogen, Phosphorus and Potassium) lost were analyzed in the laboratory. Runoff, soil and nutrients data were statistically analyzed using one way Analysis of Variance in Genstat software version 13 and the means differentiated using 5 % L.S.D. A significantly lower ( $p < 0.05$ ) annual runoff in climbing beans ( $36 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ ) than bush beans ( $248 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ ) was observed. Runoff was highest at a slope of 23 -25 % ( $379$  and  $48 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ ) than at 26 -29 % ( $137$  and  $18 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ ) from bush and climbing beans, respectively. Annual soil loss significantly varied at  $p < 0.05$  between bush ( $548 \text{ kg ha}^{-1} \text{ yr}^{-1}$ ) and climbing ( $121 \text{ kg ha}^{-1} \text{ yr}^{-1}$ ) beans. Similarly, soil nutrient losses were significantly ( $p < 0.05$ ) much higher in bush (TN=  $1.87 \text{ Kgha}^{-1} \text{ yr}^{-1}$ ; TP= $0.6 \text{ Kgha}^{-1} \text{ yr}^{-1}$ ; TK= $0.12 \text{ Kgha}^{-1} \text{ yr}^{-1}$ ) than climbing (TN=  $0.49 \text{ Kgha}^{-1} \text{ yr}^{-1}$ ; TP= $0.1 \text{ Kgha}^{-1} \text{ yr}^{-1}$ ; TK= $0.03 \text{ Kgha}^{-1} \text{ yr}^{-1}$ ) beans. Climbing beans contributed to higher increase of SOC, soil structure and high net decrease in soil N over bush beans at the end of the two seasons. Therefore, cultivating climbing beans are more environmentally friendly and beneficial crop husbandry strategy in soil and water conservation as part of the integrated watershed management approach however, their nitrogen uptake is higher than bush beans. Climbing beans should be promoted at middle slope position/above over bush beans in order to have a double benefit of soil erosion control and increased yield however, if bush beans are to be planted, then IWM practices should be promoted and implemented in the catchment by local government, farmer groups and SWC NGOs operating in the catchment.

## **CHPATER 1: INTRODUCTION**

### **1.1 Background information**

Land degradation is a global problem and an immense challenge to sustaining the biological, economic and social services provided by various ecosystems (Banadda, 2010) in watersheds. Sub-Saharan Africa (SSA) has continued to experience land degradation resulting from the destructive, extractive, over-exploitation and inadequate conservation practices (Tenywa and Bekunda, 2009). This has continued to threaten its agricultural productivity, biodiversity, water and soil quality (Scherr and Yadav, 1995) as well as the livelihoods of the poor, of whom 90 % depend on natural environment for their survival (World Bank, 2008) in most of its watersheds. Land degradation has been estimated at about 65 % of agricultural land in Africa; 45 % in South America; 74 % in Central America; and 35 % in Asia (CGIAR, 2003). Therefore, land degradation particularly due to soil erosion in Africa is a major factor of watershed quality deterioration. Soil erosion has been estimated to damage \$26 billion annually of productive soils in the continent (Lal, 2001); and in East Africa, soil erosion has been estimated to affect 50 % of the total arable land area especially in the highland areas (Ovuka, 2000). IFPRI (2001) estimates that 12.5 million hectare (ha), which is 62.5 % of land area in Uganda is under agriculture and 97 % of this land suffers from human-induced land degradation problems which has fascinated most of the watershed degradation in SSA.

Farmers are becoming increasingly concerned about the declining fertility of the soil in the highlands of Sub-Saharan Africa (Batino, 2004) and Banadda (2010) noted that decline in soil fertility is affecting about 88 % of the rural population that survive on less than 2 ha per family, constituting over three million small-scale holdings. This

has led to continuous intensive cultivation due to limited arable land in the watersheds; and farmers have experienced declining crop yields over seasons (Mugendi *et al.*, 1999). Soil erosion has created severe limitations to sustainable agricultural land use since it reduces on-farm soil productivity hence enhancing food insecurity (Moges and Holden, 2006; and Bewket, 2007) in most SSA countries including Uganda. Human activities have triggered these losses (Bewket and Geert, 2005) and this has been associated with the increasing population growth, inadequate attention to the basic watershed natural resources and the need to maximize production to meet the needs of the growing population (Feoli *et al.*, 2002). This widespread problem has also threatened soil and water quality and sustainable development in most of the different watersheds hence raising both farmer and scientists' environmental concerns over land and water quality. Consequently, many investigations have been carried out to observe soil erosion mechanism to develop methods that prevent sediment transport to water streams in the watersheds (de Vente *et al.*, 2008).

In Uganda, soil erosion has been documented as the most severe and extensive form of land degradation; erosion and the depletion of nutrients are the major contributors to declining agricultural productivity as well as degradation (Pender *et al.*, 2004). Magunda and Tenywa (2001) highlight activities like leaving the soil bare through uncontrolled bush burning and crop harvesting (Isabirye *et al.*, 2007) being the major causes of erosion. Water erosion is the most prevalent form in many parts of Uganda (Majaliwa *et al.*, 2003) and one of the leading concerns under the hilly and mountainous farming systems (Price Martin *et al.*, 2011). The tolerable annual loss rate for Africa of 4–20 t ha<sup>-1</sup> (Morgan, 1995) has been exceeded especially in the

highland areas of SE and SW Uganda (Magunda, 1996); IFPRI, (2004) estimates average annual soil losses of more than 30 tons per ha in the highlands of Uganda.

The situation has become more critical in SW part of Uganda which forms part of the frail mountainous humid tropical areas of Sub-Saharan Africa (FARA, 2009). Agriculture and agricultural related activities are the main occupation of the people; it is estimated that over 90 % of the population is engaged in agriculture (Niringye *et al.*, 2005); and agricultural production has continued to decline over the years in this region characterized by intensively cultivated steep degradation prone hill slopes (Nkonya *et al.*, 2009). Unless the current trends of land degradation are dramatically reversed, the situation for the majority of farmers incarcerated in a vicious cycle of poverty, food insecurity and natural resource degradation is likely to be aggravated in the watersheds. Reversing the situation requires adoption of integrated watershed management strategies which involve improvement of social security (food security) and economic security without compromising the environmental security; akin to introduction of cover crops like climbing beans (*Phaseolus Vulgaris L*) and bush beans (*Phaseolus Vulgaris L*) which have been attributed to economic, social and environmental security in SW Uganda; hence being dominantly cultivated (PABRA, 2007).

Climbing beans (*Phaseolus Vulgaris L*) and bush beans (*Phaseolus Vulgaris L*) are still the cheapest sources of protein in SSA making them one of the crops that are universally grown across a wide range of agro-ecological zones (CIAT, 1997). They are predominantly grown under subsistence farming on areas ranging between 0.1 and 0.6 ha in Africa (Waniale and Muramira, 1999). Over 4 million hectares of land is cropped to beans annually in Africa by smallholder farmers providing food for more

than 100 million in rural and poor urban communities, with annual per capita bean consumption in East Africa (50-60 Kg) being the highest in the world (ISAR, 2011). Beans provide a significant and growing source of income for rural households in Africa, whose annual sales are worth over US\$ 580 million (PABRA, 2007). Common beans have a per capita consumption of about 50 Kgyr<sup>-1</sup> (Siriri, 1999) than meat, 6 Kgyr<sup>-1</sup> in Uganda hence they are a very important protein source to Ugandans.

In Africa, according to Wortmann *et al.* (1998), bean cultivation is concentrated at altitudes above 1000 masl, with adequate amounts of precipitation (> 400 mm of rain) during the crop growing season; these are the cooler highlands and the warmer mid-elevation areas of East, Central and Southern Africa. However, crop area in lower elevations (<1000masl) has also been increasing following population pressure. Eastern and southern Africa region has the second highest bean production of 25% globally after Latin America. The region also has the highest per capita consumption of beans, about 50 kg/person per year in Africa (Kimani *et al.*, 2005). However, this crop together with maize is grown on almost 50% of the arable land in Uganda (CIAT, 2008). Common bean production and yields are highest in Uganda compared to the top ten African producing countries in Africa with the current yield of 4,946 Hg/ha (FAO, 2010).

Farmers in Uganda have adopted bean improved technologies developed under the following thematic areas: Increasing yield; improving resistance to drought, pests and diseases, low soil fertility; less cooking time varieties and improving nutritional value (Kalyebara *et al.*, 2004) to cope up with the alarming problem of land degradation and land scarcity especially in the SW highland region of Uganda and to reduce on food insecurity and poverty. The most adopted bean types of recent in the SW highland

areas are climbing beans which were developed by CIAT from Rwanda and promoted to SW highlands of Uganda in the early 1990s (CIAT, 2008). Climbing beans yield two – four times and are characterized by high vegetation cover over the bush beans (Buruchara, 2007). However, the shorting coming of these beans is that they require stakes to support their growth and stakes availability in the region is a challenge; hence this limits their yield potentials. PABRA, (2006) is heavily promoting these types of beans over bush beans in the region; hence bean production is expected to increase at a rate sufficient to meet the growing needs in this region. However, the efficiency of promoted climbing beans to bush beans in reducing runoff, soil and nutrient losses, and contribution to soil structure stabilization, organic matter contribution needs to be assessed.

## **1.2 Statement of the problem**

Water erosion has been acknowledged by farmers to be the major factor of natural resources degradation in Bufundi catchment. Soils in the catchment have been severely degraded and their fertility has progressively declined due to extensive cultivation along the slopes especially at the mid slope which is evidently being replaced with Eucalyptus. A high population density ranging between 250 and 500 people per square kilometre on land and other natural resources for agriculture and settlement is continually increasing making arable land scarce in the catchments. Increasing population and food demands have led to encroachment of steep slopes for major food crops; newly introduced climbing beans and the bush beans which farmers attribute to continually accelerating erosion over the later. Climbing beans were developed and are heavily being promoted by CIAT across the humid highland areas of SW Uganda and yield two to four times higher than bush beans.

Climbing and bush beans are intensively grown across the middle landscape position in Bufundi sub-catchment and the highlands of SW Uganda as compared to other annual crops. However, the agricultural practices do not always incorporate adequate soil conservation measures consequently accelerating erosion rates down the catchment and increasing the chances of water resources degradation and soil fertility decline. However, if climbing beans and bush beans are grown with appropriate agricultural practices, they have the potential of conserving soil and improving its fertility since they are cover crops which protect direct rain drop impacts and at the same time fix nitrogen into the soil as well as being used as food security crops in the catchment.

Despite of the fact that bean studies have been conducted on climbing and bush beans under different thematic areas, these studies have largely centered on improving yields, improving resistance to drought, pests and diseases, low soil fertility; less cooking time varieties and improving nutritional value and in many cases ignoring the role of these types of beans in controlling erosion and nutrient losses down the catchment. On the other hand, the studies that have targeted on soil erosion under different cropping systems have largely remained broad on annual crops. Therefore, detailed information on the rate at which the individual annual crop as for the case of climbing beans efficiently control erosion down the catchment as opposed to the bush beans continually being cultivated in the catchment has not been clearly documented hence the need for study.

### **1.3 Justification of the research**

The population density in Bufundi catchment is rapidly growing ranging between 250 and 500 people per square kilometre (DWD, 2010) against the gradually decreasing

arable land resources due to soil and nutrient depletion and erosion effects as compared to the other catchments in Southwestern Uganda (FARA, 2009). This has resulted into increased food insecurity, economic instability and catchment degradation (Fungo *et al.*, 2011) among others. Many hill-slopes are evidently degenerating into bare hills evidently being replaced by eucalyptus trees in Bufundi sub catchment. This is due to intensive cultivation of annual crops; and the major annual crops cultivated are climbing and bush beans (major food security crops) at the middle land scape position along which cultivation is intensive and degradation is visible as compared to other landscapes with limited soil and water conservation measures (FARA, 2009). To reverse the impending food insecurity, economic instability threats and degradation, several efforts to reduce soil and nutrient losses as well as pollution loading need to be established, implemented and strengthened collectively in the catchment.

Given the low use of fertilizers in Bufundi catchment as compared to other catchments in Kabale district (FARA, 2009), the increased cultivation of legume cover crops (climbing and bush beans) in the catchment can help to improve soil fertility through reduction of runoff, soil and nutrient losses as well acting as food security crops; especially for the case of climbing beans which have been proven to be high yielding; hence becoming of the integrated watershed management strategies which can be adopted in the catchment without employing expensive soil and water conservation technologies.

However, data on the rate at which these climbing beans proven to be high yielding as opposed to bush beans control runoff, soil and nutrient losses down the catchment need to be scientifically and empirically documented. In addition, the effects of these

two types of beans on soil properties also need to be assessed in order to carefully plan for sustainable soil and water conservation. This in the long run reduces watershed degradation down the streams hence promoting environmental sustainability which is the first principle of integrated water resources management.

#### **1.4 Hypotheses**

- i. Climbing beans are not significantly better than bush beans in reducing runoff generation down slope.
- ii. The annual amount of soil and Nitrogen losses through erosion is not significantly different between the bean types.
- iii. The soil organic carbon content of soils cropped to climbing beans is not significantly different to that under bush beans after the two rainfall seasons.

#### **1.5 Objectives of the research**

##### **1.5.1 General objective**

The general objective of this study was to assess the effects of climbing and bush beans' cultivation on runoff, soil and nutrient losses and soil properties at the middle landscape position in Bufundi sub-catchment.

##### **1.5.2 Specific objectives**

- i. To determine runoff from bush beans and climbing beans at the middle slope position in Bufundi sub-catchment.

- ii. To examine soil and nutrient losses from bush beans and climbing beans at the middle slope position in Bufundi sub-catchment.
- iii. To evaluate the effect of climbing beans and bush beans on selected soil physical and chemical properties

## **1.6 Significance and anticipated output**

Understanding the effects of climbing and bush beans' cultivation on soil and nutrient losses in an erosion prone area is important in finding household solutions of coping with the twin problems of soil degradation and food security. This study is therefore appropriate in contributing towards finding the environmentally and beneficial crop husbandry strategy that takes care of soil and water conservation in an integrated watershed approach in the highland areas of South Western Uganda. This in the long run promotes sustainable land use management at a level of a farm and a catchment as well as adding value to knowledge sharing initiatives within the catchment in the field of soil and water conservation studies.

These results from the study are very useful to the local government, NGOs and researchers in Bufundi sub-catchment and other highland areas where climbing beans are being promoted to revise policies and laws on soil and water conservation practices using the most cultivated legume cover crops which are the climbing beans and bush beans.

The findings guide farmers through the researchers, NGOs and local government to determine which of the climbing beans and bush beans as cover crops bring faster and tangible benefits in terms of integrated soil fertility management and income while sustaining the natural resource base.

## **1.7 Scope and limitations**

Spatially, the study was conducted in the water catchment of Lake Bunyonyi within Bufundi catchment, Kabale district, SW Uganda for two rainfall seasons of March to July and September to December, 2012. The study concentrated on soil erosion reduction at the middle landscape position using legume cover crops commonly cultivated; climbing and bush beans in the catchment; through assessing the contribution of these cover crops in reducing runoff, soil and nutrient losses (Nitrogen, Phosphorus and Potassium) down the catchment streams. The study also focused on the effects of climbing and bush beans' cultivation on soil structure and chemical properties (pH, nitrogen, exchange phosphorus, exchangeable potassium and bases). Precipitation received and rain days during the study were recorded using non recording rain gauge throughout the year of study. The limitations of the study included plant cover monitoring, root depth measurement, rainfall intensity and duration, and nitrogen leaching. The study did not also consider control treatment (bare land surface/grass land) because it was basically a comparative study between climbing and bush beans.

## CHAPTER 2: LITERATURE REVIEW

### 2.1 Introduction

This chapter reviews empirical work done by different scholars in the area of soil erosion assessment to aid watershed management and agriculture productivity improvement. It also identifies research gaps for the study. It covers areas such as soil erosion and agriculture in a watershed, factors controlling erosion rate, soil physical and chemical properties and reviews the past studies conducted on climbing beans and bush beans technologies.

### 2.2 Soil erosion and crop productivity in a watershed

Soil is the main basis for agriculture production and food security (Brunner *et al.*, 2008). Land degradation by erosion is one of the main causes of soil fertility decline and hence causing reduction in crop yields in many parts of the world watersheds (Syers, 1997). Soil erosion is defined as the detachment of soil particles by direct action of raindrops and runoff water, and transportation of these particles by splash and very shallow flowing water to channels or rill (Durán *et al.*, 2010). Soil erosion is widely considered the most serious form of degradation posing significant threat to the world's food production capacity and global food security (Biggelaar *et al.*, 2004), exerting both physical and chemical effects. Physical effects include soil erosion from cultivated fields and deposition in streams and water bodies while chemical effects involve loss of plant nutrients and other chemicals from the watershed both at the up and down stream. Soil erosion is a widely known cause of low productivity through topsoil, water and nutrient losses (Gorji *et al.*, 2008). Cumulatively, soil erosion

adversely affects water quality in the catchment streams and valleys (Gobin *et al.*, 2002) thus impacting negatively on the viability of the underlying ecosystems.

The major causes of erosion in most of the Sub Saharan Africa watersheds are inappropriate agriculture practices, deforestation, overgrazing, land abandonment (Grimm *et al.*, 2002) and amongst these factors, agricultural land use generate the highest erosion yield (Cheng, 2002, Pardini *et al.*, 2003, Garcia-Ruiz, 2010, Nunes *et al.*, 2011). However, soil erosion is also exacerbated by other human activities.

Erosion is mainly accelerated by rainfall intensity (Nyssen *et al.*, 2005). When rainfall intensity exceeds infiltration capacity, water runs off superficially (Vignola, 2005). Natural physical features like slope form; slope steepness and length also affect erosion and sedimentation transport (de Vente *et al.*, 2005). Loss of soil through erosion reduces the ability of soil to hold water hence resulting into nutrient losses; consequently affecting productivity negatively in most cases. Soil erosion has been a serious environmental problem for the past decade due to population growth (Pimentel, 2006); and its measures have rarely been adopted at a watershed level (Floor, 2000) hence there is lack of good/quality data on erosion contributing to the limited attention (Evans, 2002) in Africa.

In developing countries, soil erosion has set back agricultural development (Posthumus and Stoosnijder, 2009) especially at a watershed level. For example, a study by IFPRI (2000) indicates that soil degradation has already had significant impacts on the productivity of about 16 % of the world's agriculture land especially in African countries, where the majority of the population is dependent on agriculture. Therefore, prevention of soil erosion is one of the most essential requirements for

sustainable agriculture in the developing countries (Brunner *et al.*, 2008). In the recent years, it has been widely recognized that more site-specific approaches are needed to assess variations in erosion susceptibility in order to select the most suitable land management methods for individual hill slope section. Many studies have reported on the detrimental effects of soil erosion on agricultural productivity; and a review of the erosion data collected in intense, mechanized agricultural systems suggests that erosion reduces productivity on average by about 4 % for each 10 cm of soil lost (Bakker *et al.*, 2005). Studies have also shown that on a per ha basis, 22 kg N, 2.5 kg P and 15 kg K are being lost annually as a result of long-term cropping with little or no external nutrient inputs and returned crop residues in SSA (Smaling *et al.*, 1993; Weight and Kelly, 1998).

Silgram *et al.* (2010) study on hillslope scale surface runoff, sediment and nutrient losses associated with tramline wheelings on both sandy and silty clay loam soils across two seasons showed that tramline wheelings represented the dominant pathway for surface runoff and transport of sediment, phosphorus and nitrogen from cereal crops on moderate slopes. Results indicated that 5.5–15.8 % of rainfall was lost as runoff, with 0.8–2.9 kg TP ha<sup>-1</sup> lost along the runoff; 0.0–0.2 kg TN ha<sup>-1</sup>, 0.3–4.8 tha<sup>-1</sup> and 0.003–0.3 tha<sup>-1</sup> sediment was lost from tramline treatments, and plots without tramlines respectively.

Angima *et al.* (2003) study conducted in at the Kianjuki catchment in central Kenya on corn–bean (*Zea mays*–*Phaseolus Vulgaris* L), coffee (*Coffea arabica*), and banana (*Musa sapientum*) indicated that total annual soil loss ranged from 134Mgha<sup>-1</sup> per year for slopes with average *LS*-factors of 0–10 to 549Mgha<sup>-1</sup> per year for slopes with average *LS*-factors of 20–30. The author in the study does not highlight how

much of the soil loss was contributed by beans and the tool used for soil loss predication was a decision support tool using secondary data. The difference with this study is that it adopted experimental approach (primary data) and assessed the contribution of climbing and bush beans to soil loss. It further looked at the runoff and nutrient losses from each bean type.

Kimaro *et al.* (2008) study indicates that mean soil loss due to interill and rill erosion is highest at the mountain ridges ( $88 \text{ t ha}^{-1} \text{ yr}^{-1}$  and  $210 \text{ t ha}^{-1} \text{ yr}^{-1}$ ) as compared to 49 and  $116 \text{ t ha}^{-1} \text{ yr}^{-1}$  in the foothills, respectively. In Kenya, nutrient loss studies due to surface runoff and soil erosion from annual crops have been conducted in the highlands of central Kenya and Zobisch *et al.* (1995) study revealed that soil available phosphorus and exchangeable potassium losses under maize crop were reduced to 24.2% (28.3%), under beans to 15.3% (15.4%) and under intercrop to 9.3% (10.7%). The study did not capture the effects of beans on runoff and soil loss as well as nitrogen loss down the catchment; it also never looked at the effects of these annual crops on soil stability; hence creating a gap which this study looks into all these aspects on the two different types of beans.

In Uganda, soil erosion has been recognized as the most severe and extensive form of land degradation; and together with depletion of nutrients is the major contributors to declining agricultural productivity (Pender *et al.*, 2004). Magunda and Tenywa (2001) highlights activities like leaving the soil bare through uncontrolled bush burning and crop harvesting (Isabirye *et al.*, 2007) being the major causes of erosion. However, water erosion is the most prevalent form in many parts of Uganda especially in the highlands of south western and eastern Uganda (Majaliwa *et al.*, 2003; Bamutaze, 2005); and the tolerable annual loss rate for Africa of  $4 - 20 \text{ t ha}^{-1}$  (Morgan, 1995) has

been exceeded in these highland areas (Tukahirwa, 1996; Magunda *et al.*, 1997). However, site-specific, short-term measurements have indicated relatively low rates of physical erosion in the Kigezi highlands (Bolwig, 2002). Zake and Nkwiine (1995) reported soil erosion rates of  $126 \text{ t ha}^{-1}$  for annual crops around the Lake Victoria catchment. This finding was backed up by Lufafa *et al.* (2003) who reported highest soil loss in annual crop land use of  $93 \text{ tha}^{-1}\text{yr}^{-1}$ ; the author used a decision support tool; GIS to assess soil loss and was not specific on the contribution of each annual crops to soil loss; nutrient losses and soil structure. In this study, it adopted the experimental approach at plot scale in the catchment and also explored the effects of annual crops specifically climbing and bush beans on runoff and nutrient losses which the previous study did not explore. Isabirye *et al.* (2007) study on soil losses due to cassava and sweet potato harvesting estimates soil and nutrient loss of  $3.4 \text{ tha}^{-1}$  and  $0.2 \text{ tha}^{-1}$  soil loss; Nitrogen =  $1.71$  and  $0.14 \text{ kgha}^{-1} \text{ harvest}^{-1}$ , Phosphorus =  $0.16$  and  $0.01 \text{ Kg ha}^{-1} \text{ harvest}^{-1}$ , Potassium =  $1.08$  and  $0.15 \text{ Kg ha}^{-1} \text{ harvest}^{-1}$  for cassava and sweet potatoes, respectively. In this study, the author measured soil loss and nutrient losses at plot scale which this study also adopted however; the difference is that the author did not consider legumes and runoff which this study considered. The study was also carried out in moderately flat area which is completely different from this study carried out in the highland areas.

Bamutaze (2011) study on patterns of water erosion and sediment loading in Manafwa catchment indicates that mean annual runoff rates at plot scale varied from  $45 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$  to  $332 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ , averaging  $135 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$  at all sites and soil losses from the annual cropping and perennial cropping systems were  $1127 \text{ kg ha}^{-1} \text{ yr}^{-1}$  and  $549 \text{ kg ha}^{-1} \text{ yr}^{-1}$ , respectively. The author conducted the study at plot scale and broadly looked

runoff and soil loss from annual crops hence need for the study which was specific on climbing and bush beans' effects on runoff and soil losses; also considered these crops' contribution to nutrient losses control and Soil Organic Carbon which the previous author did not explore.

### 2.3 Factors controlling erosion rate

The factors controlling soil erosion are; erodibility of the soil, erosivity of the eroding agents (runoff, wind and rainfall), slope, plant cover and management practices (Mark *et al.*, 1998); and these factors involve parameters used to derive the Universal Soil Loss Equation (USLE), (Wischmeier and Smith, 1978). USLE is related to rainfall and runoff erosivity factor (R), soil erodibility factor (K), slope length factor (L), slope steepness factor (S), cover management factor (C), and support practice factor (P).

$$A = R * K * LS * C * P \dots \dots \dots \text{Equation 1}$$

In recent years, different authors have used soil erodibility (K factor) as an indicator of soil erosion (Parysow *et al.*, 2001, 2003) because soil erodibility is a measure of soil susceptibility to detachment and transport by the agents of erosion. These processes are influenced by soil properties, such as particle size distribution, structural stability, organic matter content, soil chemistry and clay mineralogy and water transmission characteristics (Tejada and Gonzalez, 2006).

### 2.4 Vegetation cover and soil erosion

Vegetation cover is an important parameter used in assessing the relationship between vegetation and soil erosion. However, the intensity of soil erosion actually changes

not only with vegetation cover but also with differences in vegetation type and structure (Zhongming *et al.*, 2010).

Cover crops protect the soil against splash erosion and physical degradation like aggregate destruction, topsoil compaction and surface sealing (Baets *et al.*, 2011); the role of vegetation cover in protecting the soil from erosion has long been recognized (Morgan, 2005) in that it reduces water induced soil erosion by intercepting rainfall, increasing water infiltration on associated soil fertility hill slopes, intercepting runoff at soil surface level and stabilizing the soil by roots (Gyssels *et al.*, 2005).

Water loss through runoff in most types of soils and climatic conditions is more associated with the management of the soil cover; and many authors have demonstrated that in a wide range of environments both runoff and sediment loss decrease exponentially as the percentage of vegetation cover increases (Nunes *et al.*, 2011). The authors highlight that arable land and coniferous afforestation soil cover are the most seriously affected in terms of runoff and soil erosion hence vegetation dynamics emerging as a key factor in quantifying and interpreting erosion response to land use cover.

Durán *et al.* (2010) study indicates that runoff is highest in *Rosmarinus officinalis* vegetation cover (41.7 mg ha<sup>-1</sup> yr<sup>-1</sup>) and lowest in native spontaneous vegetation (3.2 mg ha<sup>-1</sup> yr<sup>-1</sup>); heaviest nutrient losses in runoff and eroded soils being from the bare soil and lowest in *Lavandula dentata* vegetation cover. For annual cover crops, Sasal *et al.* (2010) indicate that soybeans monocultures vegetation cover contribute to higher runoff coefficient than pasture (6.25-fold), and the author concludes that water loss through runoff is more associated with the management of surface cover.

Therefore, vegetation cover especially increase in shoot density as well as root density decrease exponentially the rate of concentrated flow of erosion rates since protection of the soil surface in the early plant growth stages is crucial with respect to the reduction of water erosion rates (Gyssels and Poesen, 2003); above ground vegetation decrease erosion through interference of raindrops and influence on soil structure (de Vent *et al.*, 2005) and below ground roots achieve soil erosion reduction by building up the soil, improving soil structure through soil roughness to increase infiltration (Glyssel *et al.*, 2003). While past studies on the extent and severity of erosion are voluminous, detailed data on the effects of individual annual crops especially beans which are commonly grown in Africa on erosion control in the highland areas remains not clearly documented at the catchment level hence the need for the study on the effects of climbing and bush bean cultivation on soil erosion control.

## **2.5 Crop productivity and Soil physical and chemical properties**

Land use practices affect the distribution and supply of soil nutrients by directly altering soil properties (Murty *et al.*, 2002). Majaliwa *et al.* (2010) explains that the change from natural forest cover to tea and eucalyptus induces changes in top soil properties like exchangeable Mg and Ca, available P, SOM, pH, and bulk density of sub soil. Land use/type cover influences soil organic matter evolution which is vital indicator of soil quality and it has implications on soil properties like aggregate stability, infiltration and aeration rates, microbial activity and nutrient release; soil organic carbon is closely related to soil shear strength and cohesion (Boye and Albrect, 2001) properties which plays a great role to resist erosion. Therefore, decrease in soil organic matter translates to adverse effects like compaction, water logging and structure degradation (Troeh *et al.*, 1999).

## **2.6 Soil structure and crop productivity**

Soil structure is greatly affected and manipulated by agricultural management practices (Papadopoulos *et al.*, 2006). Soil is said to have a good structure when it has stable aggregates (LaI, 1991); and according to the author, soils with large aggregates expressed in terms of high MWD (mean weight diameter) indicate good soil structure; however, soil erosion process carries loose fine soil and organic matter particles which on deposition lead to sealing of surface compaction and poor aggregates. Soil structure however, determines the accessibility of air, water and nutrients for plant roots, the drainage of the soil, the ability of the soil to resist the erosive forces of wind and rain (Papadopoulos *et al.*, 2006) as well as the ease and depth to which roots can penetrate the soil to access water and nutrients. Hence management of soil structure within the watershed is very critical to agricultural production and environmental management.

## **2.7 Crop productivity and Soil Organic Carbon**

Increasing human population pressure has decreased the availability of arable land and it is no longer feasible to use extended fallow periods to restore soil fertility in the watersheds of Sub Saharan Africa; The fallow period which would have restored soil fertility and organic carbon is reduced to lengths that cannot regenerate soil productivity leading to the non-sustainability of the farming systems (Nandwa, 2003).

High population densities have necessitated the cultivation of marginal lands (steep slopes of the highlands) that are prone to erosion hence enhancing watershed degradation through soil erosion and nutrient mining. Bationo *et al.* (2006) urges that to reverse the declining agricultural productivity while preserving the environment for

present and future generations must begin with soil fertility restoration and maintenance; Soil organic carbon (SOC) is concurrently a source and sink for nutrients and plays a vital role in soil fertility maintenance (Bationo *et al.*, 2007).

Roose and Barthes (2001) closely link soil fertility to soil organic matter, whose status depends on biomass input and management, mineralization, leaching and erosion and the authors continue to recognize that soil organic matter increases structure stability, resistance to rainfall impact, rate of infiltration and faunal activities within the watershed hence conserving the environment as well as encouraging social and economic welfare development in the long run within the communities through improved agricultural productivity.

Therefore, soil organic carbon is an index of sustainable land management (Woomer *et al.*, 1994; Nandwa, 2003); it is not only a major regulator of various processes underlying the supply of nutrients and the creation of a favourable environment for plant growth but also regulates various processes governing the creation of soil-based environmental services (Vanlauwe, 2004). SOC content declines due to continuous cultivation, erosion, runoff and leaching (Roose and Barthes, 2001). Therefore it is of great importance to stock SOC in the soil through minimizing erosion and runoff.

To maintain food production for a rapidly growing population, crops like legumes which contribute to high biomass and the effective recycling of organic amendments such as crop residues and manures are essential for the smallholder farming systems that rely predominantly on organic residues to maintain soil fertility; and legume based cover crops have been underlined for controlling erosion, and enriching the soil in organic matter and nitrogen in Africa (Carsky *et al.*, 2001).

The environmental challenges in many rural areas of Sub-Saharan Africa include reducing deforestation, improving soil organic matter storage especially in cultivated soils and reducing erosion which are closely related to organic carbon balance in the plant-soil-atmosphere system (Barthes *et al.*, 2004); Therefore, optimum management of the soil resource for provision of goods and services requires the optimum management of organic resources and the soil organic carbon (SOC) pool (Vanlauwe, 2004) for food security.

## **2.8 Past studies on climbing and bush beans**

The diversity of conditions under which beans are grown coupled with highly specific local preferences for particular seed type or colors have complicated attempts at bean improvement. As a result, for over twenty years research has identified a number of improved varieties and agronomic practices that increase yields and resistance to pests and diseases within diverse agro-ecological environments and the greatest progress has been in breeding for the resolution of diseases (Teverson, 2003), insects/pests management (Nchimbi-Msolla *et al.*, 2000; Ursula, 2007) and nutritional constraints (Katungi *et al.*, 2009) and improvement in yield potential (Graham, 1997).

The present review considers the origin/evolution and production environments of *Phaseolus Vulgaris L* (Wortmann *et al.*, 1998; Buruchara, 2007; Buruchara *et al.*, 2011), the cropping systems used for bean production (CIAT, 1997; and Bavec *et al.*, 2000), the agronomic and biological factors which most limit crop yield (Bavec *et al.*, 2000; Maingi *et al.*, 2001), the traits usually considered in bean improvement programs (Kimani *et al.*, 2003), impacts of recent molecular advances to crop improvement on the prospects for the improved production of this grain legume

(Musandu and Ogendo, 2000; Xavery *et al.*, 2005; Sidik and Njiwa, 2005; PABRA, 2007).

In addition to the later bean studies, socio-economic aspects of beans have been studied by different scholars (Wanda and Ferris, 2004; CIAT, 2008).

Buruchara *et al.* (2011), states that the versatility of the bean crop and its contribution to a household's food income, diet, health and even environmental security is remarkable hence the future evident priorities for bean research and extension are: scaling out of recent research advances, increasing productivity, enhancing market linkages, and improving knowledge management and utilization (CIAT, 2008). Therefore, from the reviewed literature on bean studies, information on the effects of bush and climbing beans on soil erosion control in the humid, tropics are not clearly documented as it is the case of Bufundi sub catchment.

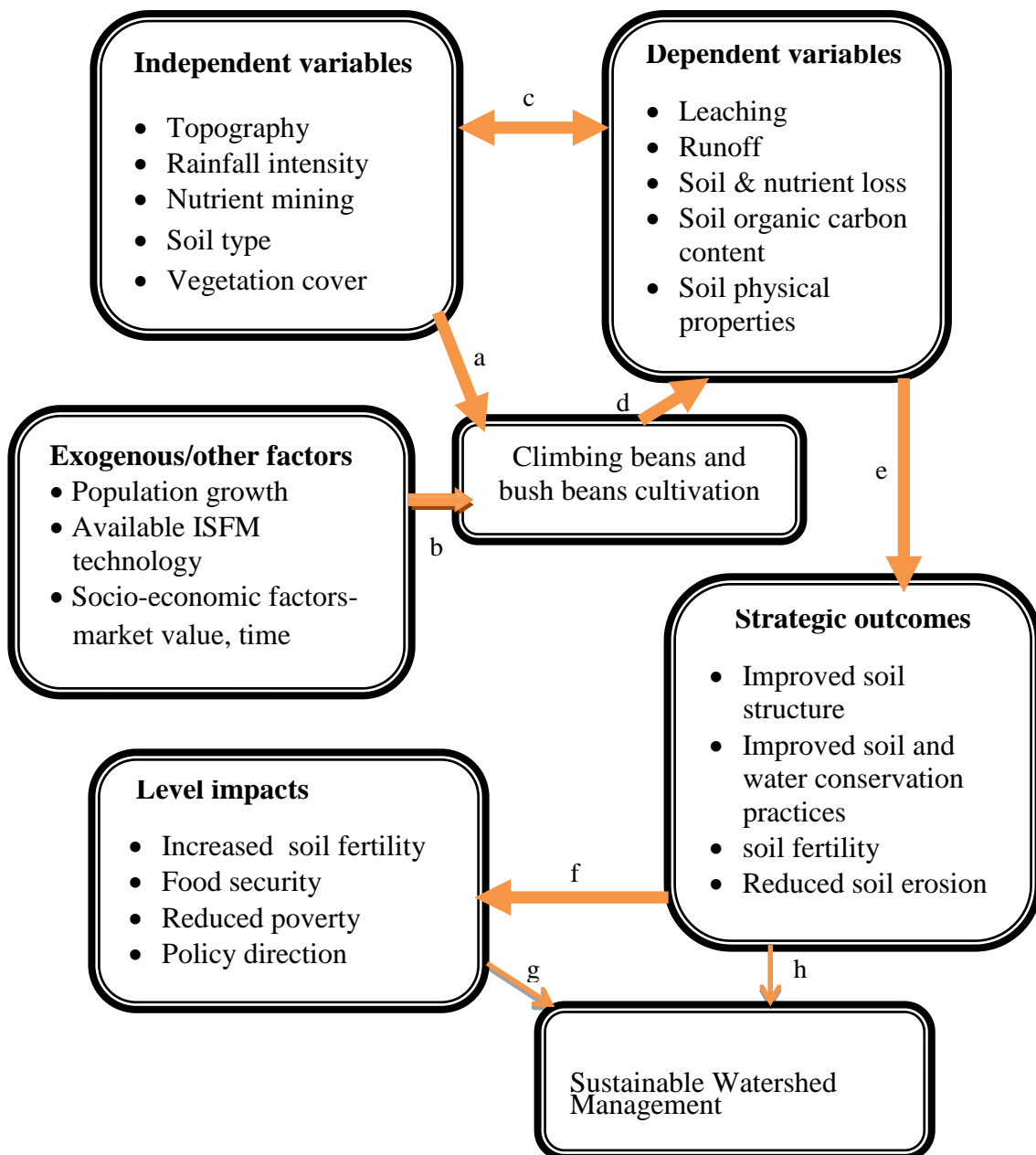
## **2.9 Conceptual framework for climbing beans and bush beans cultivation on soil and nutrient losses**

Theoretically, soil erosion in a watershed is influenced by various factors which can be natural like topography (Papiernik *et al.*, 2005), rainfall intensity (Basher and Rosi, 2001), nutrient mining and soil type (Rorke, 2000) and exogenous factors such as socio-economic factors, available integrated soil fertility management practices and population pressure (Nkonya, 2002). These factors have influence on crop production and soil and water conservation as is the case for climbing and bush bean cultivation (Arrow b, c) in most watersheds like Southwestern Uganda.

Beans cultivation in this region has been highly promoted (PABRA, 2006) because of soil cover, littering and biological nitrogen fixation (BNF) characteristics, market

value and food security due to the increasing population pressure. However, continued bean cultivation together with rainfall intensity, topography, nutrient mining and soil type influence nitrogen leaching, vegetation cover, soil and nutrient losses, soil physical properties (soil structure, bulk density and soil organic matter and carbon content) (Siriri *et al.*, 2005) within the sub catchment (Arrows c,d).

Therefore, it is important to study the quantitative links between bean cultivation and soil erosion in order to understand the extent to which bean cultivation influence the dependent variables (runoff, soil and nutrient losses, Soil Organic Carbon, soil properties and leaching) in the sub catchment (Arrow d). This linkage can contribute to improved soil and water conservation practices, soil structure, and erosion reduction in the catchment (Arrow e). In the long run, there will be improved soil fertility, food security hence reducing poverty, guide in policy direction (Arrow f,g,h). If these are achieved, then there is sustaining integrated watershed management. These links are illustrated in Figure 2.1



**Figure 2.1: Conceptual framework of climbing beans and bush beans cultivation on soil and nutrient losses**

Source: Synthesized conceptual framework from literature review (Author, 2013)

## **CHAPTER 3: MATERIALS AND METHODS**

### **3.1 Introduction**

This chapter covers the methods and materials used during the study which include description of the study area, experimental design, field data collection procedures and data analysis which included laboratory analysis for nutrients lost along with runoff and soil, soil structure, soil organic carbon and soil chemical properties; nitrogen, available phosphorus, exchangeable potassium, magnesium, exchangeable sodium, soil pH and calcium and statistical data analysis using ANOVA and F test from Gens tat version 13 as the analytical tool.

### **3.2 Study area**

#### **3.2.1 Location of the study area**

Bufundi Catchment is geographically located in Kabale district, South Western Uganda between latitudes  $1^{\circ}$  and  $1^{\circ} 34''$ S and longitudes  $29^{\circ} 18''$ E and  $30^{\circ} 9''$ E; it covers up to  $20 \text{ km}^2$  (Figure 3.1).

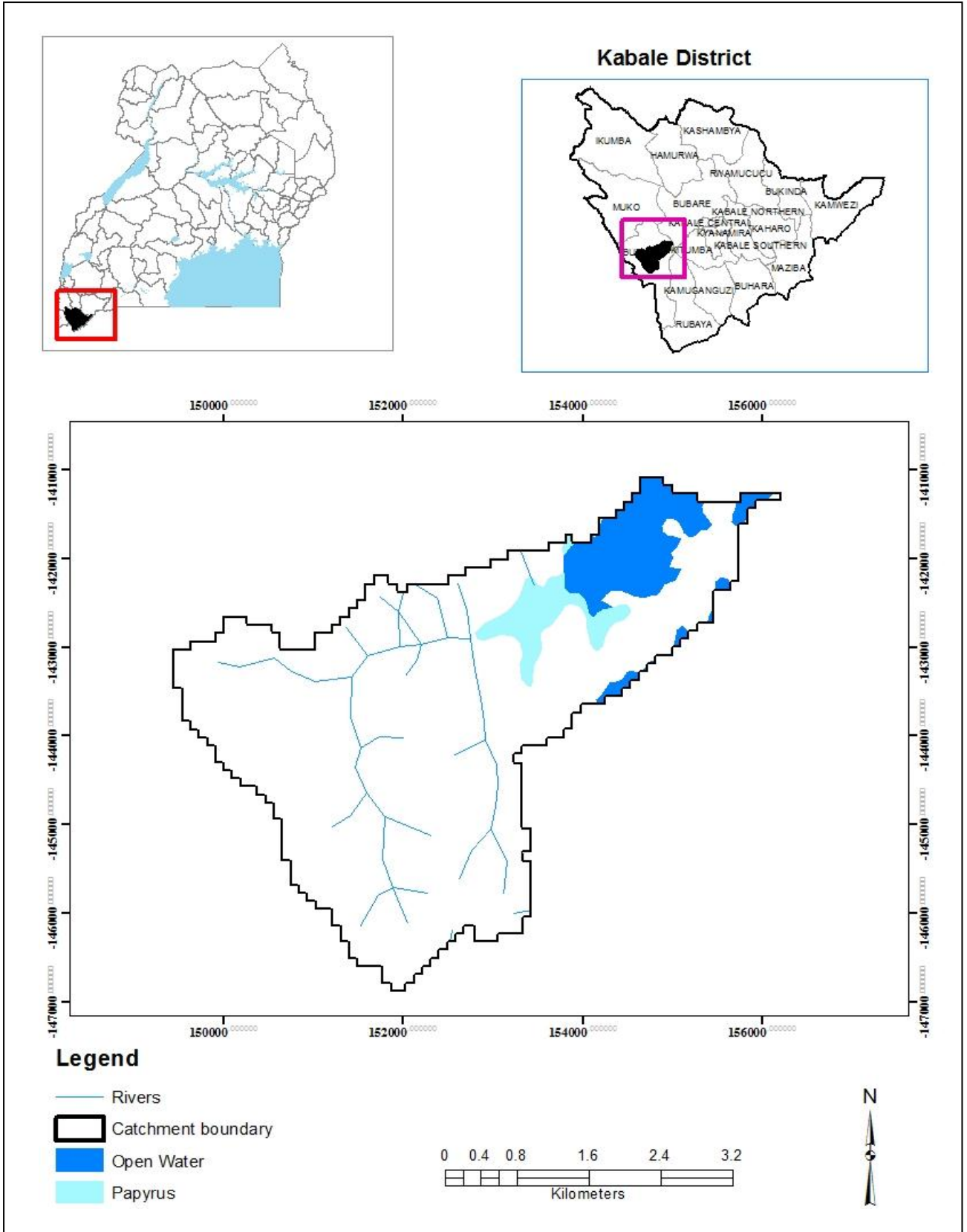


Figure 3.1: Map of Bufundi sub catchment in Southwestern Uganda

Source: Author 2013

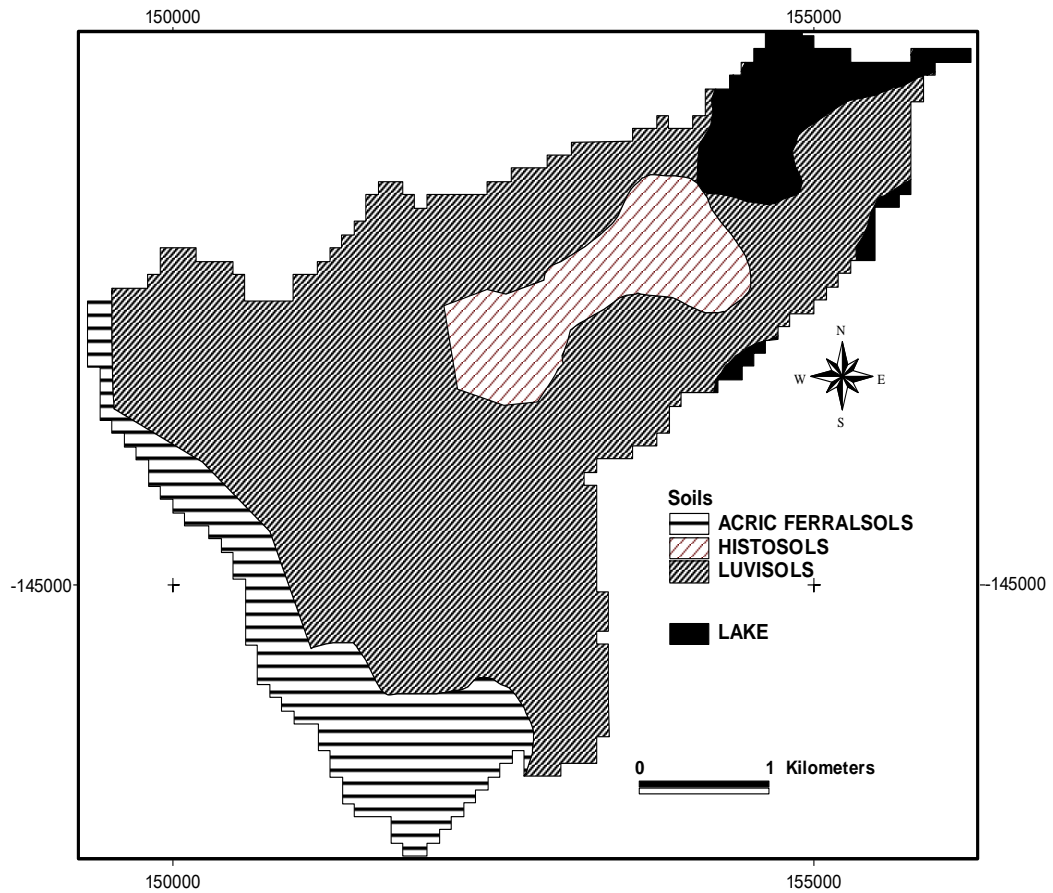
### **3.2.2 Climate**

The terrain is dominated by hills and valleys with most slopes ranging between 12 - 50 % but may go as high as 80 % (LKPLS Survey report, 2008). The catchment has a bimodal rainfall pattern that provides opportunity for two cropping seasons in a year (FARA, 2009). The “long rains” occur from mid-February through early June as first season while the “short rains” occur from mid-September to mid-December which provide the second season; The average annual rainfall in the catchment varies between 900 mm to 2200 mm with a mean annual temperature of 16.7°C (FARA, 2009).

### **3.2.3 Soil and geology of the study area**

The soils in the catchment are typically Luvisols, Histosols and Ferrasols (Figure 3.2) with declining fertility due to continuous cultivation (Wortmann and Eledu, 1999). The soils are well drained with a texture ranging from sandy clayey loam to clayey loam with a pH range of 5-5.5; and the top soil depth ranges from 5- 15 cm (FARA, 2009). The soil moisture regime is Udic isothermic (Yost and Eswaran, 1990).

Soils are relatively fertile in nature but susceptible to extreme soil erosion caused by rainfall drops (NRM-SSA-CP baseline report, 2008); and according to the same report, this catchment is drained by various means including small aquifers, various small streams and rivers in the valley bottom wetland which drain into Lake Bunyonyi. Land for cultivation in this catchment is scarce as a result of over population and land fragmentation (FARA, 2009).



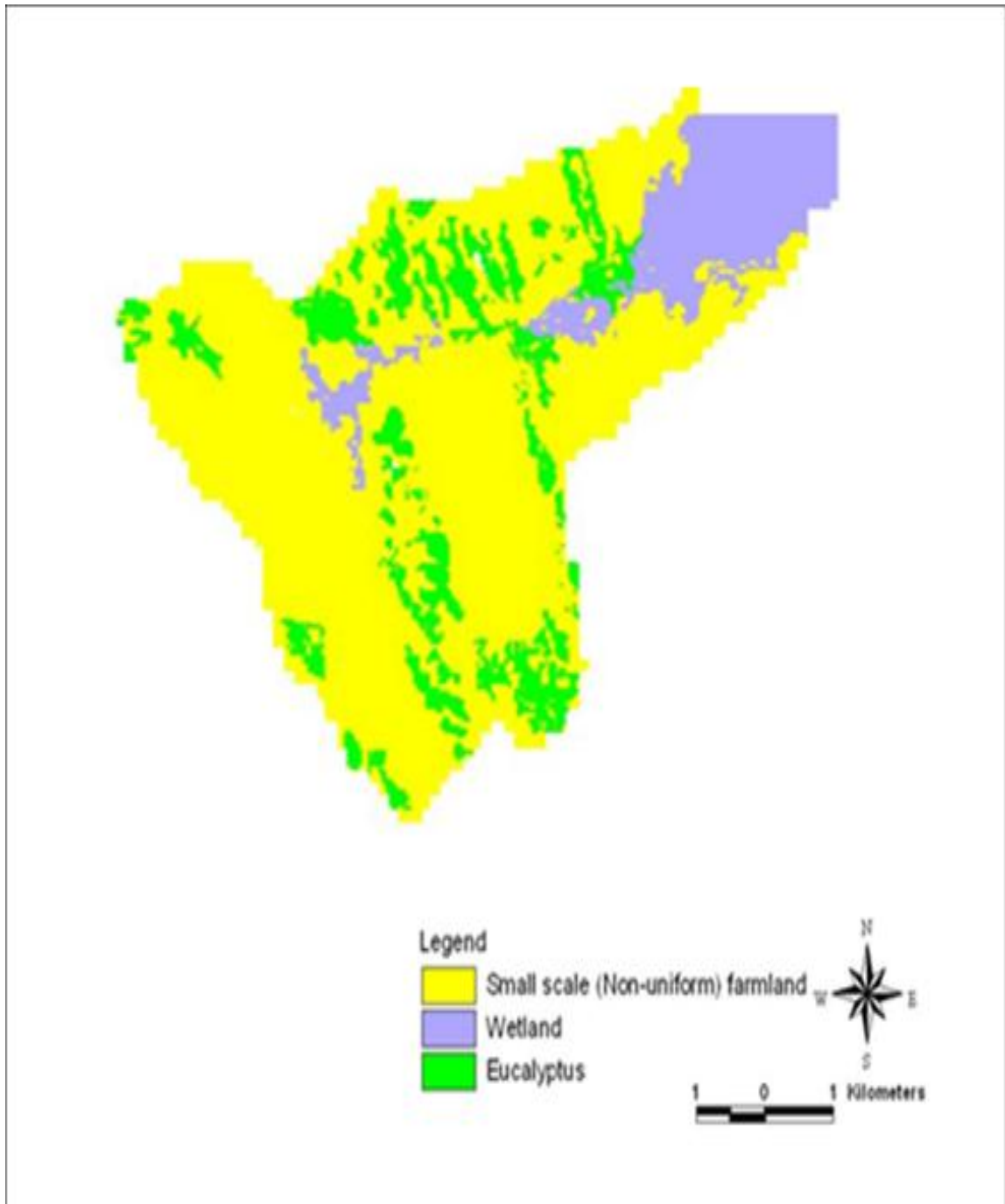
**Figure 3.2: The major soil types in Bufundi micro-catchment**

Source: FARA, 2009

### 3.2.4 Population and land use in the study area

Bufundi has a population of about 31,128 people (UBS, 2011) and with a high population density ranging between 250 and 500 people per square kilometre (DWD, 2010). The major land uses in the sub-catchment include small scale farmland, woodlots (Eucalyptus) especially on the degraded top hills and wetlands (Figure 3.3). The area is densely cultivated from hilltops to the valleys including stream banks and subsistence agriculture is the major activity employing about 84% of the population (UBS, 2011). The major crops grown include: potatoes, climbing and bush beans,

maize, sorghum, barley and wheat at small scale farmlands. After exhaustion and severe degradation, the formally arable hill-slopes that are unproductive patches are planted with eucalyptus (FARA 2009).



**Figure 3.3: The Major land uses cover in Bufundi sub-catchment**

Source: FARA, 2009

### **3.3 Experimental Approach**

Soil, runoff and nutrient losses from the climbing and bush beans were quantified using the runoff plot approach. Runoff plots remain one of the most widely applied methods for estimating field erosion rates over short and medium time periods (Boix-Fayos *et al.*, 2006). The approach is efficient when demonstrating to farmers that erosion is much less from a plot which has a good vegetative cover than that with low vegetative cover (Boix-Fayos *et al.*, 2006).

The runoff plot approach is also good at comparative studies (Boix-Fayos *et al.*, 2006). This method was appropriate for this study because it was comparing how climbing and bush beans control runoff, soil and nutrient losses down the catchment. However, the method has limitations of unreliable data due to errors in construction, field measurement and destruction of the plots (Bamutaze, 2011,). This was dealt about by following the construction guidelines adopted by Bamutaze, (2005) and constructing the plots close to the farmer's settlement for easy access during data collection. The plots were regularly repaired with the silt, pipes and receptacles cleaned. Several authors; Kizza *et al.* (2013); Ghahramani *et al.* (2011); Sasal *et al.* (2010) have conducted studies under different land uses, land scape positions using this runoff plot scale and appreciated its reliability hence adopting this method for the study.

#### **3.3.1 Experimental layout**

The experiment was conducted at the middle land landscape position for two bean growing seasons (Long rains season which starts from March – July and short rains seasons commencing from September – Mid December) in 2012. Three farmers were

purposively selected from the catchment in Kacerere village with the terraced sites having slope range of 23 – 29 % measured using a clinometer at the middle landscape position. The study terraces and slope ranges are representative of those commonly found in the study area with a toe drain measuring 12 – 15 m long. Middle landscape position was selected because bean cultivation activities in this area are carried out at this landscape position due to the fact that there is no flooding to affect the performance of beans. While at the lower slope, it is majorly settlements and in the valley, mainly Irish potatoes are cultivated with the upper slope position being occupied by eucalyptus (FARA, 2009). A total of 18 closed erosion plots of 2 x 9 m (six erosion plots on each farmer's site) were established (Plate 3.1 and 3.2).



**Plate 3.1: Constructing runoff plots**

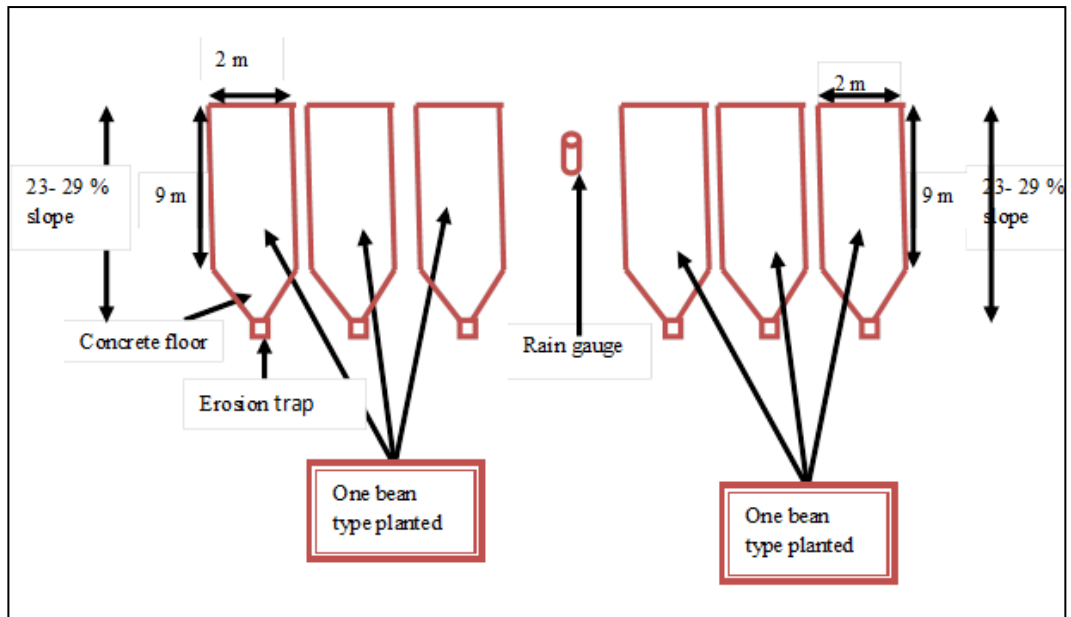
Source: Author (2013)



**Plate 3.2: Constructed runoff plots**

Source: Author (2013)

Each plot consisted of an iron sheet enclosure, sediment and run off collector and 5 litre jerry can for storing run off. The boundaries of each plot were defined by 0.3 m x 3 m iron sheet directing the runoff to the collecting system and inserted up to 10 cm below the soil surface to prevent soil and water from leaving or entering the plot according to Durán *et al.* (2011). To avoid the effects of position, all the plots were established in one line, oriented parallel to the slope and adjacent to each other and this was similar to the designs of Durán *et al.* (2011) and Kizza *et al.* (2013). Two treatments, climbing beans (NABE 7c, Local name: ‘Kigome’) and bush beans (NABE 7c, Local name: ‘Kigome’) were planted within the closed erosion plots (Figure 3.4) with a blanket addition of MAK rhizobia strain for common bean to booster their growth.



**Figure 3.4: Field runoff plots' lay out**

Source: Boix-Fayos *et al.*, (2006)

The planting grid was 45 cm x 20 cm for both types of beans, with approximately 81 introduced plants per closed plot at a sowing rate of one seed per hill. At each farmer's site, a rain gauge was installed to measure the amount of rainfall after every rainfall event for computation of the ratio of runoff to rainfall amount received per day. Farmers managed the plots like any other field in order to be representative of the management across the catchment.

### 3.3.2 Experimental design

The run off plots were replicated three times for each treatment at each farmer's site in order to minimize errors and increase precision during the measurement of runoff, soil properties, and soil and nutrient losses measured.

### 3.4 Data collection procedures

#### 3.4.1 Runoff, soil and nutrient loss determination

Runoff was collected through erosion collecting system according to Durán *et al.* (2011) which consisted of a metallic trap; with 5 litres clean plastic tank connected at the end of the collecting plastic pipe located at the subsequent end of the trap after 15 days of planting; this was because at this stage, bean leaves would be well established. The sampler collection was designed to collect about 4 % of the total runoff. However, each of the sampler was individually recalibrated at plot level by simulating runoff with a known amount of water and measuring the recovery rate through the silt to the pipe and finally into the receptacle (Kizza *et al.*, 2013), (Plate 3.3).



**Plate 3.3: Calibration of the runoff plots**

Source: Author (2013)

The amount of runoff was determined using a measuring cylinder after each rainstorm event after allowing the sediment to settle according to Kizza *et al.*, (2013). All the water and sediments that collected in the jerry can were then put into a clean bottle which later was delivered to Makerere University soil science laboratory for analysis of soil loss and nutrients; total nitrogen, total phosphorus and total potassium lost along with this soil. Data on soil and nutrient losses from climbing and bush beans were achieved by filtering the runoff samples for the different months within the season in the laboratory.

### **3.4.2 Determination of the coefficient of transmission**

The runoff plot coefficient of transmission was estimated. The coefficient of transmission was calculated as a fraction of volume of water reaching the outlet and the portion collected in the collection system during the recalibration (Bamutaze, 2011). To determine the coefficient of transmission, a known volume of water was gently poured around the compacted runoff plot area and their associated collected runoff (Kizza *et al.*, 2013). This was repeated three times to minimize errors and increase precision of the transmission coefficient.

### **3.4.3 Soil physical- chemical parameters determination**

Soil physical and chemical parameters assessed included soil structure (mean weight diameter index), soil organic matter, nitrogen, available phosphorus and exchangeable potassium and bases, respectively.

In each farmers' plots, four composite soil samples at (0–15 cm and 15 -30 cm); two composite samples from each type of bean plots at each farmer's site were sampled using the soil auger in a Z sampling method (Hue *et al.*, 2000) to achieve

representative soil samples at the beginning of the experiment for each season, and at the end of each season.

Soil samples were also taken from each farmer's site considering the climbing beans and bush beans plots using soil auger to measure soil structure at the beginning and end of each season.

### **3.5 Description of field equipment/tools used in the study**

#### **3.5.1 Runoff pipe sampler**

The sampler according to Durán *et al.* (2011) as represented in plate 3.4 consists of pipe dividers to capture  $1/25^{\text{th}}$  of the total runoff. The dividers are in two sets of five uniform pipes. At the first set (1),  $1/5^{\text{th}}$  of the runoff is captured into one of the pipes (2) to another set of five pipes (3). At the terminal set, one of the five pipes (4) is connected to a collection vessel where runoff and soil is collected. The sampler is anchored by metallic steel (5) to the ground. However, due to the construction errors which may not guarantee  $1/25^{\text{th}}$  collection, each of the erosion plots was calibrated using a known volume of water. This gave the actual collection coefficient.



**Plate 3.4: Runoff pipe sampler**  
Source: Author (2013)

### 3.6 Data analysis

Data analysis involved three stages, that is; field analysis, laboratory analysis stage and statistical analysis stage of the field collected data and that analyzed in the laboratory.

#### 3.6.1 Field analysis

##### 3.6.1.1 Runoff measurement from bush beans and climbing beans

This objective one was achieved from the field immediately after the rain storm event. The measured volume of runoff from the measuring cylinder was multiplied by the coefficient of transmission to get the plot runoff per rainstorm event, and then extrapolated to an area of 1 hectare, by multiplying the obtained number by 555.6 which was arrived at after getting the ratio of the area of hectares in metric (10,000 m<sup>2</sup>) by the plot area; 18 m<sup>2</sup> (Equation 1). Seasonal runoff loss was obtained by summing up the different monthly runoffs registered for the different rainfall events in

the season (Equation 2) and the two seasonal runoff collections were eventually summed up to obtain the annual loss per hectare (Equation 3).

$$\text{Plot runoff(m2/ha)} = \sum_{k=0}^n (\text{runoff per rain event} \times 10000/18) \dots\dots\dots \text{Equation 2}$$

$$\text{Seasonal runoff} = \sum_{k=0}^n (\text{Monthly runoff}) \dots\dots\dots \text{Equation 3}$$

$$\text{Annual runoff(m2/ha/yr)} = \sum_{k=0}^n (\text{Seasonal runoff}) \dots\dots\dots \text{Equation 4}$$

### 3.6.2 Laboratory analysis

#### 3.6.2.1 Soil and nutrient losses analysis from climbing and bush beans

This objective two was achieved following analytical procedures by Okalebo *et al.* (2002) in the laboratory which were performed as follows:

At the end of each bean growing season, runoff samples from the two types of beans for the different plots were bulked per month in the laboratory and then halved into two portions; where the first portion was for sediment analysis from runoff and the other portion for chemical analysis of nutrients (NPK) from both sediment and runoff samples. The first portion was filtered using grade one filter paper (Plate 3.5) and the filtrate oven dried at 105 °C for 24 hours to determine the amount of sediments.



**Plate 3.5: Sediment filtration for soil and nutrient loss determination**

Source: Author (2013)

The amount of soil lost for the total rainfall events in that month was obtained by multiplying the amount of monthly sediment by monthly runoff (McDonald *et al.*, 2003) and transmission coefficient and then expressed on hectare basis. Seasonal soil loss was computed by summing up all soil losses from the individual months of the season (Equation 4). Finally, annual loss was determined by summing up the losses of the two seasons (Equation 5)

Seasonal soil loss, Kg/ha

$$= \sum_{k=0}^n (\text{Monthly soil loss} \times \text{transmission coefficient} \times \text{runoff})$$

.....Equation 5

$$\text{Annual soil loss, Kg/ha/yr} = \sum_{k=0}^n (\text{Seasonal soil losses}) \quad \text{.....Equation 6}$$

The remaining portion of the bulked monthly runoff sample was filtered using grade one filter paper and then the filtrate oven dried at 60 ° C before chemical analysis of soil nutrients lost; Phosphate-P was determined calorimetrically, Potassium-K was determined using a flame photometer and total nitrogen determined by digestion and titration (Okalebo *et al.*, 2002). The seasonal amount of nutrients lost was estimated by summing up all the monthly nutrient losses within that season and finally expressed per hectare basis. Later, the annual loss was computed by summing up the seasonal losses (Equation 6 and 7).

Runoff nutrient loss Kg/ha

$$= \sum_{k=0}^n (\text{nutrient conc.} \times \text{transmission coefficient} \times \text{runoff})$$

.....Equation 7

Soil nutrient loss Kg/ha

$$= \sum_{k=0}^n (\text{nutrient conc.} \times \text{transmission coefficient} \times \text{soil loss})$$

.....Equation 8

### 3.6.1.2 Soil physical and chemical properties analysis

This objective three was also achieved following analytical procedures by Okalebo *et al.* (2002) in the laboratory.

Soil physical properties; soil structure, soil organic carbon (SOC), and soil chemical properties; Nitrogen (N), available phosphorus (P), exchangeable potassium (K), calcium (Ca), Magnesium (Mg) and Sodium (Na) were analyzed to evaluate their losses or gains due to climbing beans and bush beans cultivation, in addition soil pH was also analyzed for each season. Available Phosphate-P was determined calorimetrically, exchangeable Potassium-K determined using a flame photometer and

nitrogen determined by digestion and titration. Soil organic carbon was determined using Walkley Black method; Soil pH was achieved using a pH meter and exchangeable bases (Magnesium, Calcium and Sodium) were determined using extraction method. Soil structure before planting and at harvesting for each season was assessed using the dry sieving technique described by Chepil, (1962), with the results expressed as Mean Weight Diameter (MWD) of the aggregates.

### **3.6.3 Statistical analysis**

#### **3.6.3.1 Runoff analysis from both climbing beans and bush beans**

To achieve this objective, monthly runoff data for each replicate was entered in excel and then exported to Genstat Discovery Version 13 for statistical analysis. Analysis of variance (ANOVA) using a completely randomized design was performed in order to ascertain whether there are differences in the means of runoff between the two bean types and the two rainfall seasons. Differences between individual means were tested using the LSD at 5 %. Dependent variables included runoff and the independent variables were rainfall seasons, rainfall, climbing beans, bush beans and slope. The F-test tool was used to prove the hypothesis that climbing beans are better than bush beans in reducing runoff generation down the catchment. This was done by establishing the differences between the individual means of soil and nutrient losses from bush and climbing beans using the 5 % LSD.

#### **3.6.3.2 Soil and nutrient losses analysis from climbing and bush beans**

This objective was also analyzed statistically using Genstat Discovery Version 13 software. Monthly soil loss and nutrient (NPK) loss data were entered into excel and transferred to Genstat Discovery Version 13 software. Analysis of variance

(ANOVA) was performed in order to determine the differences in the means of soil and nutrient (NPK) losses from the two bean types. The hypothesis that annual amount of soil and nitrogen losses through erosion is not significantly different between the bean types was tested using F-test by establishing the differences between the individual means of soil and nutrient losses from bush and climbing beans using the 5 % LSD.

### **3.6.3.3 Soil physical and chemical properties analysis**

To analyze this objective statistically, soil structure expressed as mean weight diameter (MWD), SOC, N, available P, exchangeable K and Na, Ca, Mg and soil pH data was also analyzed with the help of Genstat Discovery Version 13 software.

The soil physical and chemical properties' data were entered in excel and then exported to Genstat Discovery Version 13 software for statistical analysis. Analysis of variance (ANOVA) using a completely randomized design was performed in order to ascertain whether there are differences in the means of the different properties from both bean types during two rainfall seasons. Differences between individual means of the different properties from both bean types were tested using the L.S.D at 5 %. Dependent variables included MWD, SOC, N, available P, exchangeable K and Na, Ca, Mg and soil pH while the independent variables included; climbing beans, bush beans and the rainfall seasons. To test the hypothesis that soil organic carbon content of soils cropped to climbing beans is not greater than that under bush beans after the two rainfall seasons was also tested using the F-test tool at L.S.D (5 %).

## **CHAPTER 4: RESULTS AND DISCUSSIONS**

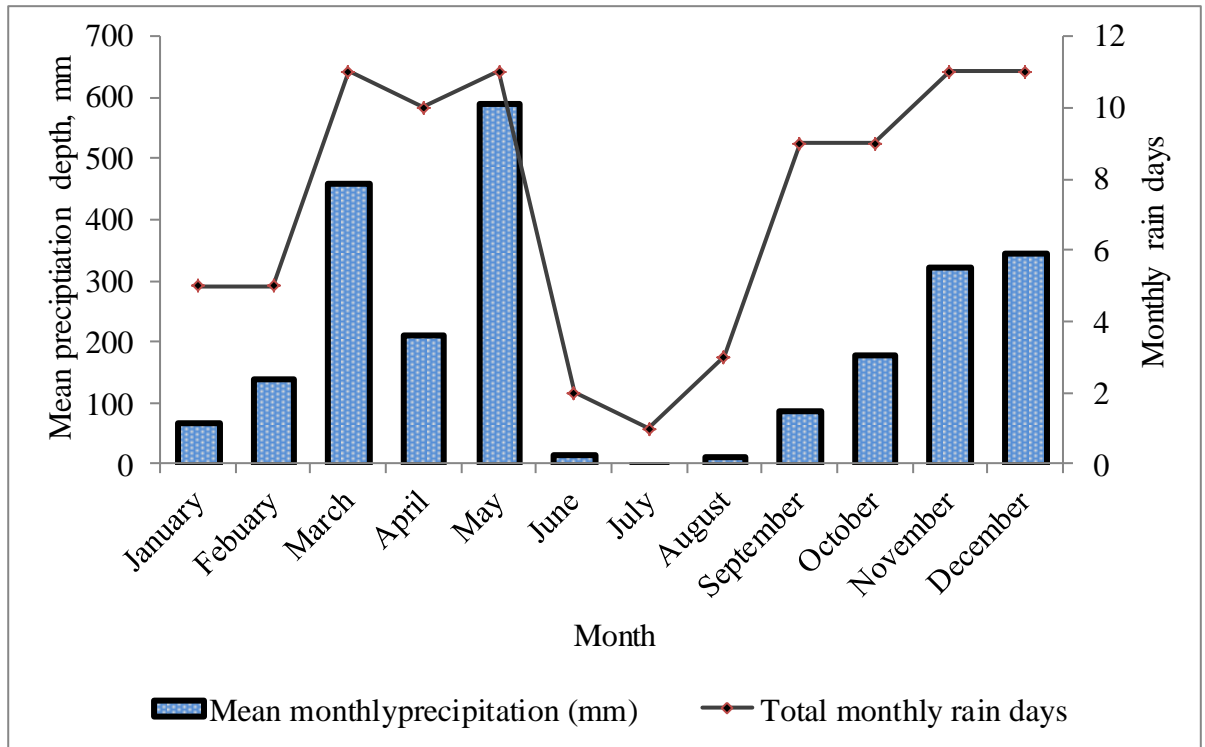
### **4.1 Introduction**

This chapter presents the results and discusses the findings from the study conducted in Bufundi Sub-catchment in SW Uganda according to the objectives. General results of rainfall received during the study period are presented. For objective one, results for runoff between the bean types for each and both seasons are presented and discussed accordingly. However, in addition to objective one, results on comparison of percentage runoff for each bean type to rainfall for each season are also discussed. Under objective two, results on soil and nutrient (NPK) losses from climbing beans and bush beans for two rainfall seasons are also presented and discussed. Lastly, for objective three, results on the effects of climbing beans and bush beans on soil structure, soil organic carbon, nitrogen, available phosphorus, exchangeable potassium and Sodium, Calcium, Magnesium and soil pH before planting and at harvest are presented and discussed.

### **4.2 Rainfall distribution and amount at the experimental site**

Rainfall is a very important factor in stimulating runoff, soil and nutrient losses along the slopes (Mzezewa and van Rensburg, 2011). Rainfall distribution during the study periods was normally distributed though the highest monthly total rainfall recorded was in the month of May, 2012 (591.8 mm) in the long rain season which also had a higher number of rain days (42 rain days) as compared to the short rain season whose highest rainfall recorded (346.5 mm) was in the Month of December, 2012 with the total rain days (40 days), (Figure 4.1). The highest amount of precipitation in the

month of May and monthly maximum rain days of 11 rain day are similar to the rainfall patterns recorded by Niringiye *et al.* (2005).



**Figure 4.1: Mean monthly precipitation and total rain days recorded during the study period (March - December, 2012)**

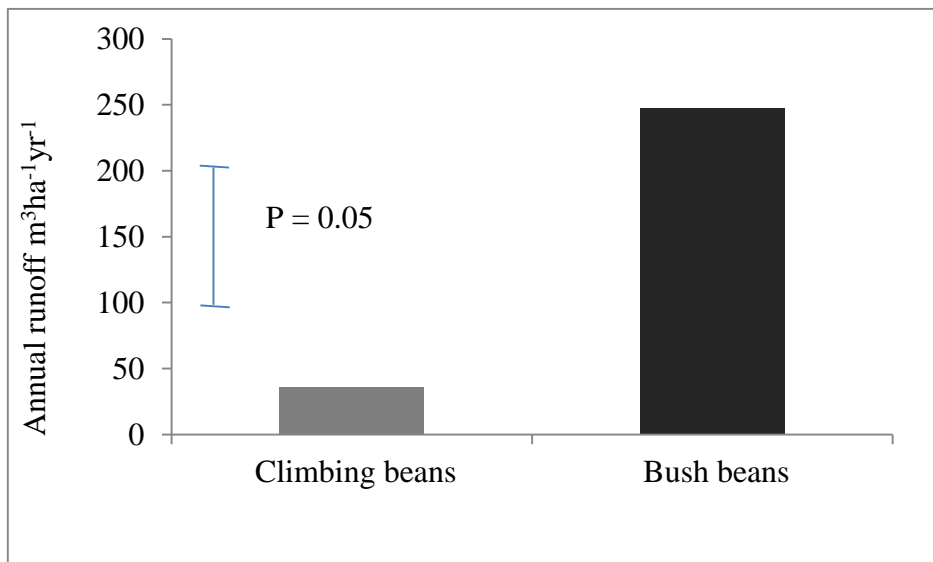
#### **4.3 Objective 1: Determination of runoff from climbing beans and bush beans**

The results for this objective included annual and seasonal runoff generation, however, in addition to the runoff generation results, percentage runoff to rainfall, and slope effects on runoff generation from climbing and bush beans are also presented and discussed in the following subsections.

### 4.3.1 Runoff generation

Results for runoff generation were determined in order to compare the amount of runoff which is controlled by the climbing beans over bush beans at the middle slope landscape position in the sub-catchment.

Annual runoff was highly significantly different ( $p < 0.05$ ) between climbing beans and bush beans (Figure 4.2).

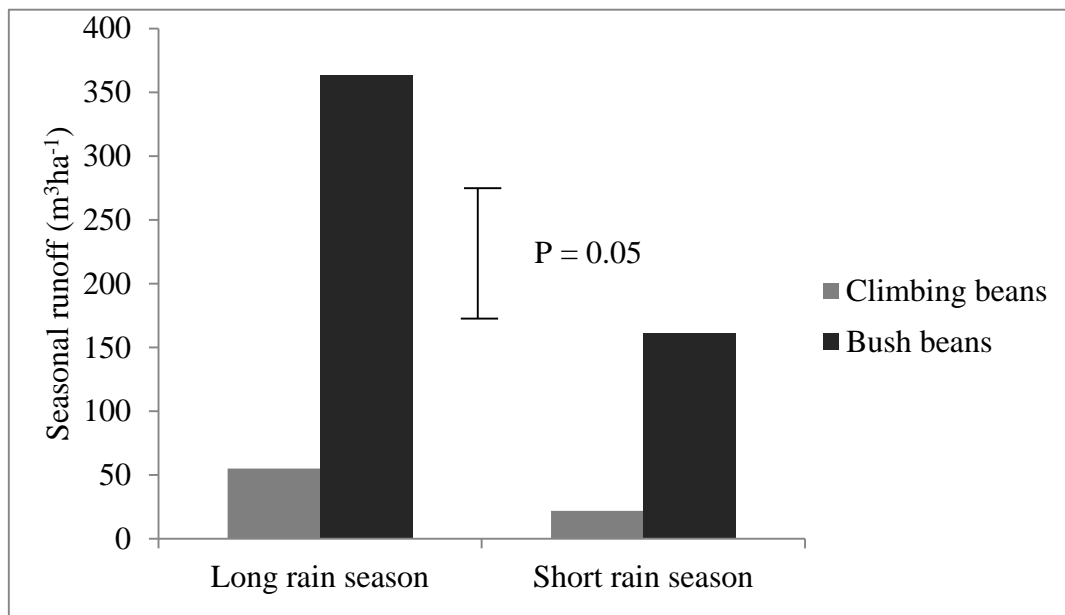


**Figure 4.2: Annual runoff generation**

Runoff generation from each of the bean growing seasons was also significantly different between climbing and bush beans at  $p \leq 0.05$  (Figure 4.3). Annual runoff generation was highest from bush beans ( $248 \text{ m}^3\text{ha}^{-1}\text{yr}^{-1}$ ) than climbing beans ( $36 \text{ m}^3\text{ha}^{-1}\text{yr}^{-1}$ ), (Figure 4.2). Therefore, runoff generation from bush beans in the study area was higher as compared to the climbing beans; hence climbing beans more runoff down the catchment. These values are in the range of the mean annual runoff ( $45$  to  $332 \text{ m}^3\text{ha}^{-1}\text{yr}^{-1}$ ) observed by Bamutaze (2011) in Mt Elgon catchment highlands

whose study was conducted almost at similar slope gradients (11.9 % to 27.9 %) especially for bush beans which are commonly grown in these catchments except that the climbing beans' runoff is lower than the author's value. The runoff values from both bean types are very low in a tropical African context. This concurs with the observations from Tukahirwa (1996) and Taylor and Howard (1999) in SW Uganda who found out very low runoff values, and related the very low values of runoff to low rainfall erosivity, high infiltration rates and high organic matter content.

Bush beans contributed the highest seasonal runoff generation of 363 and 161 m<sup>3</sup>ha<sup>-1</sup> season<sup>-1</sup> than climbing beans which contributed 55 and 22 m<sup>3</sup>ha<sup>-1</sup> season<sup>-1</sup> during the long rains and short rain season, respectively (Figure 4.3). Runoff generation was highest during the long rains season over the short rains season. This was due to the prolonged rain days (42 days) which occurred in long rains season than 40 rain days in the short rains season.



**Figure 4.3: Seasonal runoff generation**

The difference in runoff generation between climbing and bush beans could be attributed to the differences in their ground cover characteristics, which protect the soil surface from raindrop impact though the study did not monitor ground cover characteristics. However, a study conducted by Sperling and Muyaneza (1995) in Rwanda highland areas with the same terrain like Bufundi sub-catchment show that climbing beans provide a better ground cover protection than bush beans and this could be closely related to the study. Also observations in Kabale by Tukahirwa (1996) indicate that surface cover due to the density of sorghum plants greatly influence runoff. Khan, (2001) also reported that surface cover reduced soil erosion by more than 45 % in Thana, Malakand Agency. This conforms with Ghahramani *et al.* (2011) observations in Miyagase Dam in Eastern Japan where beech forest with the highest ground cover contributed less erosion rate at a plot scale than those with moderate to sparse ground cover. Zhou *et al.* (2008) work indicated that greater vegetation cover can considerably reduce runoff from high risk areas. A study by Ayed and Mohammed (2010) in Palestine indicate that forests and natural vegetation dominated by *Sarcopoterium spinosum* prevent or decrease the risk of runoff because these have greater vegetation covers.

#### **4.3.2 Hypothesis test that climbing beans are not significantly better than bush beans in reducing runoff generation**

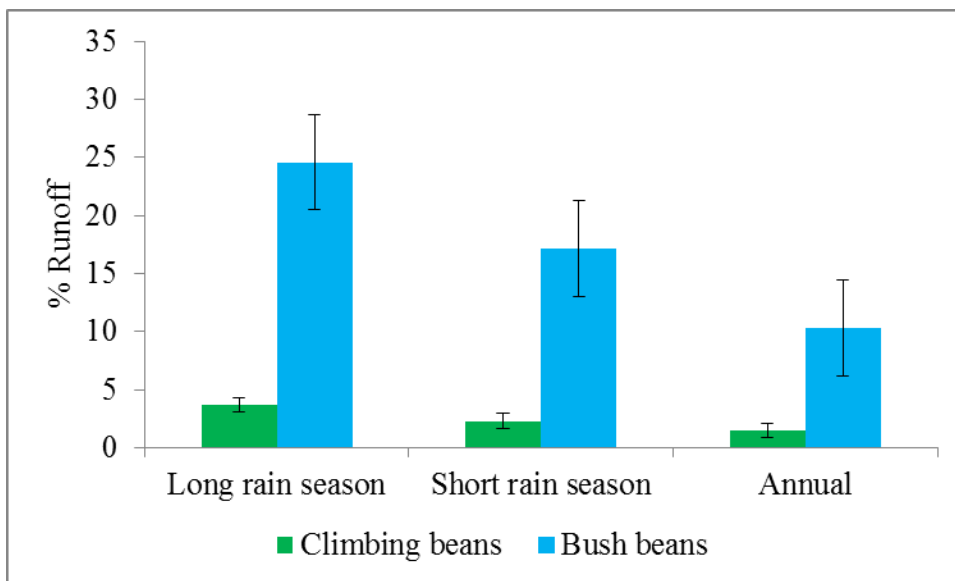
This was achieved after separating and comparing the significance levels of the individual runoff means of the different bean types using F-test at 5 % LSD. The results showed significant difference ( $p = 0.001$ ,  $d.f = 1$ ) between annual runoff and bean types (Appendix I) hence rejecting the hypothesis. Therefore, climbing beans are

significantly better than bush beans in reducing runoff generation down the catchment.

### 4.3.3 Percentage runoff to rainfall received during the study period

This sub-section is a follow up of objective one. It was conducted to assess how much of the rainfall received during the study period ended up as runoff which is also known as the runoff coefficient.

From the results, there was a significant difference ( $p < 0.05$ ) in the ratio of runoff to the amount of rainfall received between climbing and bush beans during the study period (Figure 4.4).



**Figure 4.4: Percentage runoff to precipitation depth**

The percentage rainfall that ended up as runoff ranged between 1.5 % for climbing beans in the short rains (season two) to 24.6 % for bush beans in the long rains (season one). Bush beans contributed the highest percentage of rainfall that ended up as runoff for each season and annually; 24.6 % in season one (long rains); 17.2 % in

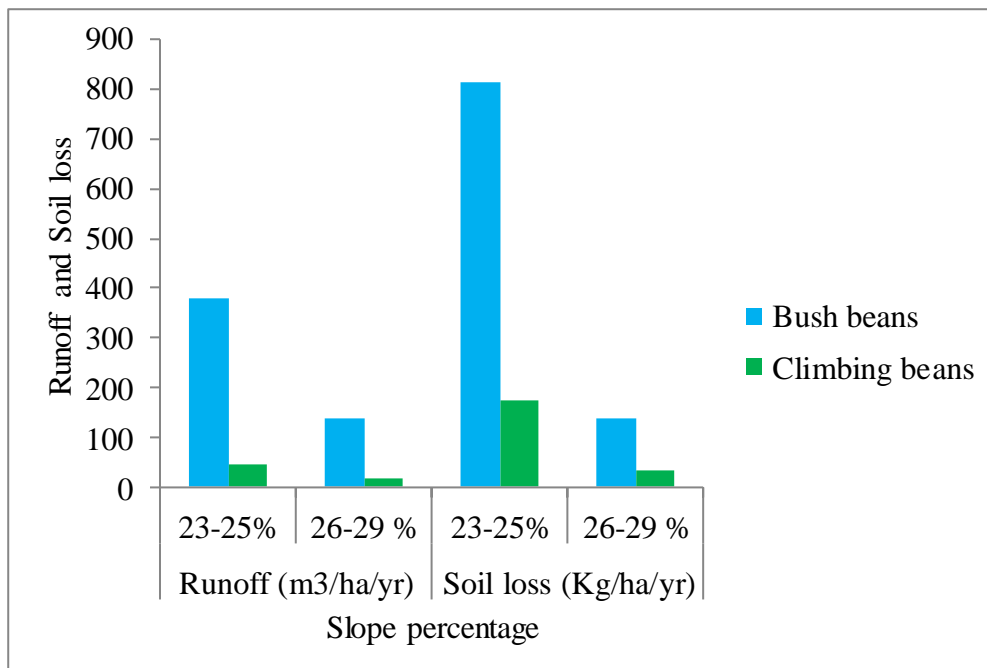
season two (short rains) and 10.3 % annually as compared to climbing beans which contributed 3.7% in season one; 2.3 % in season two and 1.5 % for annually (Figure 4.4). Overall, the highest runoff coefficient for each bean type was observed in short rains due to the less amount of rainfall and rain days received than during the long rains seasons. Similar observations were noted by Nearing *et al.* (2005) who found out that changes in rainfall amount associated with changes in storm rain days will likely have a greater impact on runoff and erosion than simply changes in rainfall amount alone.

The high percent rainfall that ended up as runoff from bush beans over climbing beans is due to the ground cover characteristics noted by Sperling and Muyaneza (1995). Also several authors (Bamutaze, 2011; Nunes *et al.*, 2011; Gimeno-García *et al.*, 2007; Xinxiao *et al.*, 2006;) who have conducted studies on ground cover effect on runoff coefficient under different land uses/cover have observed similar pattern that the higher the ground cover, the lower the runoff coefficient. Therefore, climbing beans have a high ground cover hence capable of reducing runoff down the catchment over bush beans; this translates into low runoff coefficient.

#### **4.3.4 Effects of slope on runoff generation and soil loss from climbing beans and bush beans**

This sub-section is a follow up of objective one. Though the study was carried out at the mid slope landscape, there was variations in the slope for the different replicates. Hence this sub-section assesses the effect of slope gradient on runoff generation and soil loss from both bean types.

The results showed that there was variability in mean annual runoff and soil loss with slope gradient at plot scale in the sub-catchment as depicted in Figure 4.5. The highest mean annual runoff and soil loss was generated on the low slope gradient site (379 and 48 m<sup>3</sup>ha<sup>-1</sup>yr<sup>-1</sup> runoff; 815 and 175 Kg ha<sup>-1</sup>yr<sup>-1</sup> soil loss for bush beans and climbing beans, respectively), while the lowest runoff was generated on the steep slope gradient site (137 and 18 m<sup>3</sup>ha<sup>-1</sup> yr<sup>-1</sup>runoff; 137 and 35 Kg ha<sup>-1</sup>yr<sup>-1</sup> soil loss for bush beans and climbing beans respectively). For all considered slope gradients, there was significant difference ( $p > 0.05$ , d.f = 1) in runoff generation, soil loss and slope percentage. This pattern closely conforms to that observed by Siriri *et al.* (2005) in the highlands of SW Uganda where low gradient slopes were found to be more degraded.



**Figure 4.5: Slope effect on runoff generation and soil loss**

These results are contrary to the expected pattern because moderately steep slopes are associated with high speed of runoff. This could be attributed to the intensive agricultural activities which are carried out at a relatively lower slope gradient in the

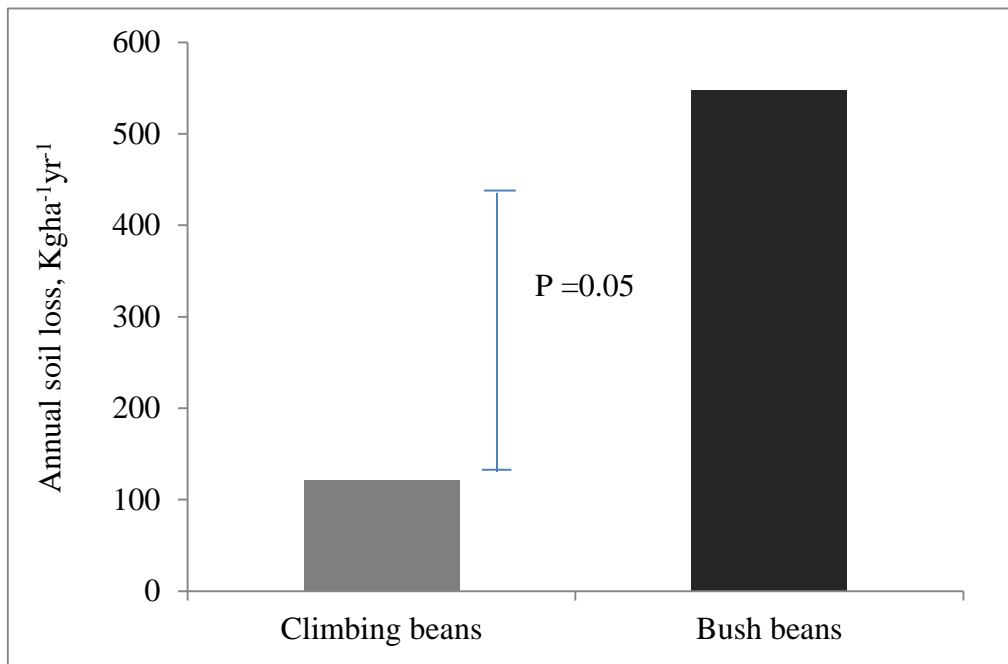
catchment because it is easy for the farmers to access than the steep slopes (FARA, 2009). In addition, the amount of runoff increases down the slope due to the increasing speed, therefore, at a relatively steep slope which is a water entry point, runoff is initiated hence the erosive power increases down the slope length (Terrence *et al.*, 2002). The low intensive agricultural activities at the steep slopes in the catchment increase the water entry potential into the soil hence reducing runoff. This is also concurs with Walter *et al.* (2007) who described the importance of water entry potential in reducing runoff. Similar conclusions have been noted by Hudson, (1995); and Bamutaze, (2011). Siriri *et al.* (2005) also noted the same observations in SW Uganda.

#### **4.4 Objective 2: Soil and nutrient losses from climbing and bush beans**

Under this objective, soil loss from each bean type during each season and annual soil loss from both seasons is presented and discussed in the following subsections.

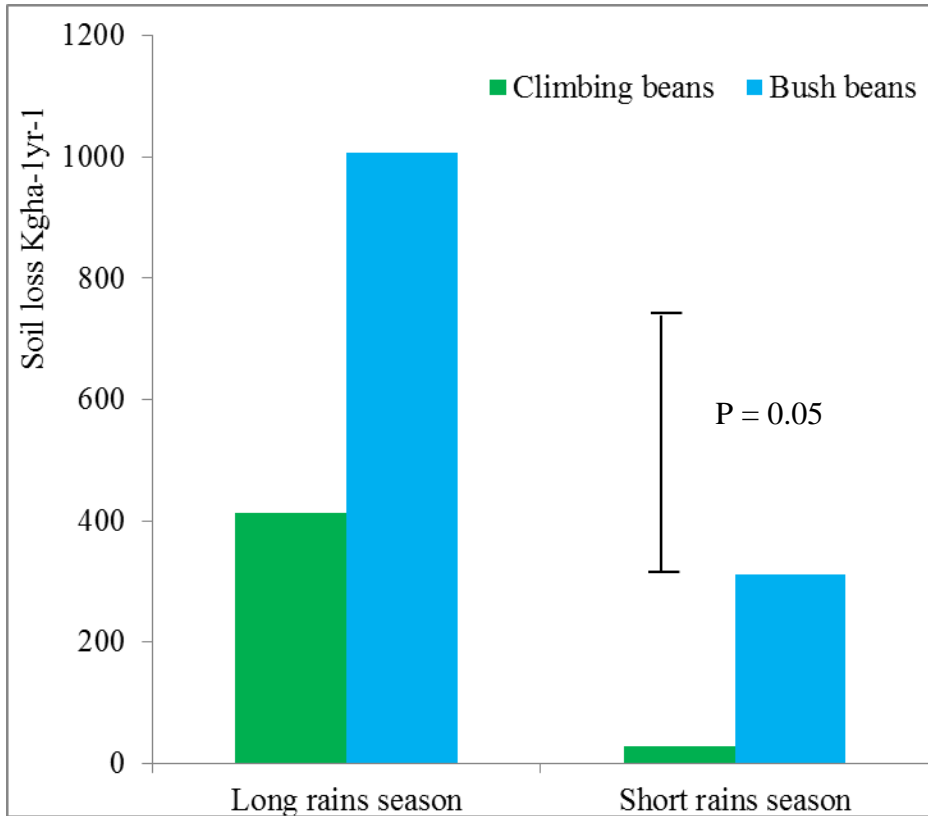
##### **4.4.1 Soil losses**

Soil loss from both bean types was analyzed for each season and annually during the study period. The results showed that the annual soil loss from the two bean types varied from 121 Kg ha<sup>-1</sup> yr<sup>-1</sup> for climbing beans to 548 Kg ha<sup>-1</sup> yr<sup>-1</sup> for bush beans (Figure 4.6). There was significant difference ( $p < 0.05$ ) between the bean types during the study period (Figure 4.6)



**Figure 4.6: Annual soil loss from climbing beans and bush beans**

Seasonal soil loss varied significantly between the two bean types ( $p < 0.05$ ). During the long rains season (season one), bush beans contributed the greatest soil loss (1008 Kg ha<sup>-1</sup>season<sup>-1</sup>) than climbing beans (413 Kg ha<sup>-1</sup>season<sup>-1</sup>); and in short rains season (season two), bush beans contributed the highest soil loss (311 Kg ha<sup>-1</sup>season<sup>-1</sup>) as compared to climbing beans (29 Kg ha<sup>-1</sup>season<sup>-1</sup>), (Figure 4.7).



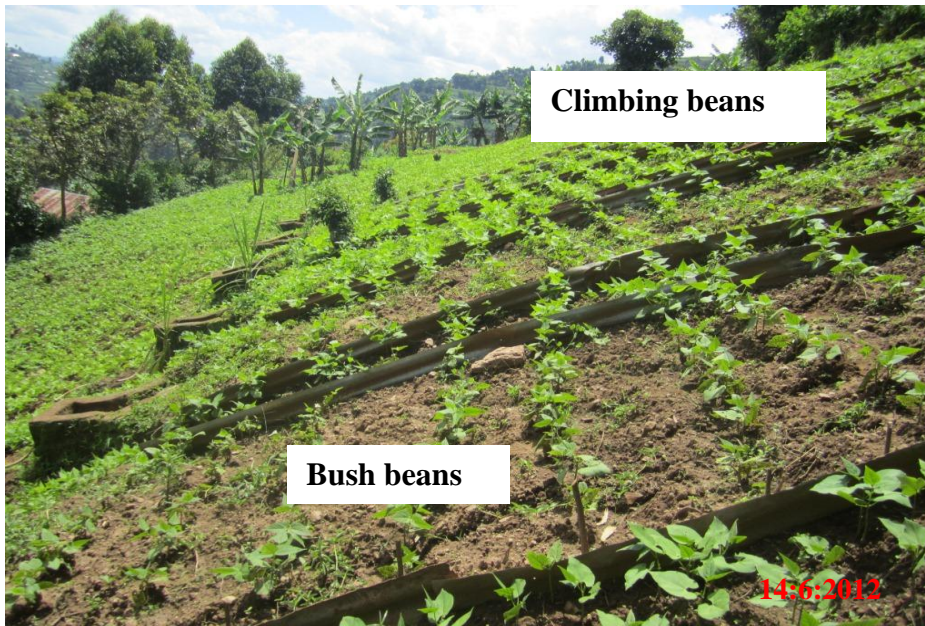
**Figure 4.7: Seasonal soil loss from climbing beans and bush beans**

Generally, there was more soil loss during long rains season (season one) than short rains season (season two). This was due to the prolonged rain days during the long rains as compared to the short rains. Similar findings were observed by Okoba and Sterk, (2006) who noted that prolonged rain days caused the temporal and spatial dynamics of soil surface level and soil loss dimensions of the rills as compared to the short rain days. Therefore, during long rain season (season one), there is high soil loss as compared to the short rain days (season one) in the catchment.

The annual soil loss from bush beans are in line with Bamutaze (2011) observations in Mt Elgon highland catchment whose soil loss was  $549 \text{ Kg ha}^{-1} \text{ yr}^{-1}$ . However, the soil loss values from the two bean types are below the proxy tolerable limit of  $5 \text{ t ha}^{-1} \text{ yr}^{-1}$  normally used in Uganda (Lufafa *et al.*, 2003; Majaliwa, 2005) or the  $10 \text{ t ha}^{-1} \text{ yr}^{-1}$

stated by Morgan (1986) for mountain environments. Therefore, the observed plot scale soil loss rates indicate that the situation in Bufundi sub-catchment is not as bad from agricultural sites in Southwestern Uganda as commonly believed. Undeniably, the observed plot scale soil loss rates in the sub-catchment are also justified by earlier findings by Tukahirwa (1996) on the slopes of Kabale in cultivated sorghum where soil loss on average were 1.4, 38.3, and 19.4 tons ha<sup>-1</sup> yr<sup>-1</sup> on the 10 %, 25 % and 45 % slope, respectively, and from other mountainous environments elsewhere (Kosmas *et al.*, 1997; and Molina *et al.*, 2007). Appraisals by Carswell (2007) on erosion in highland regions of Uganda concluded that soil erosion rates are much less than would be expected even in steep slopes. Tukahirwa (1996) related the low values to low rainfall erosivity, rainfall intensity, high infiltration rates and low soil erodibility due to favorable soil mineralogy and a stable soil structure.

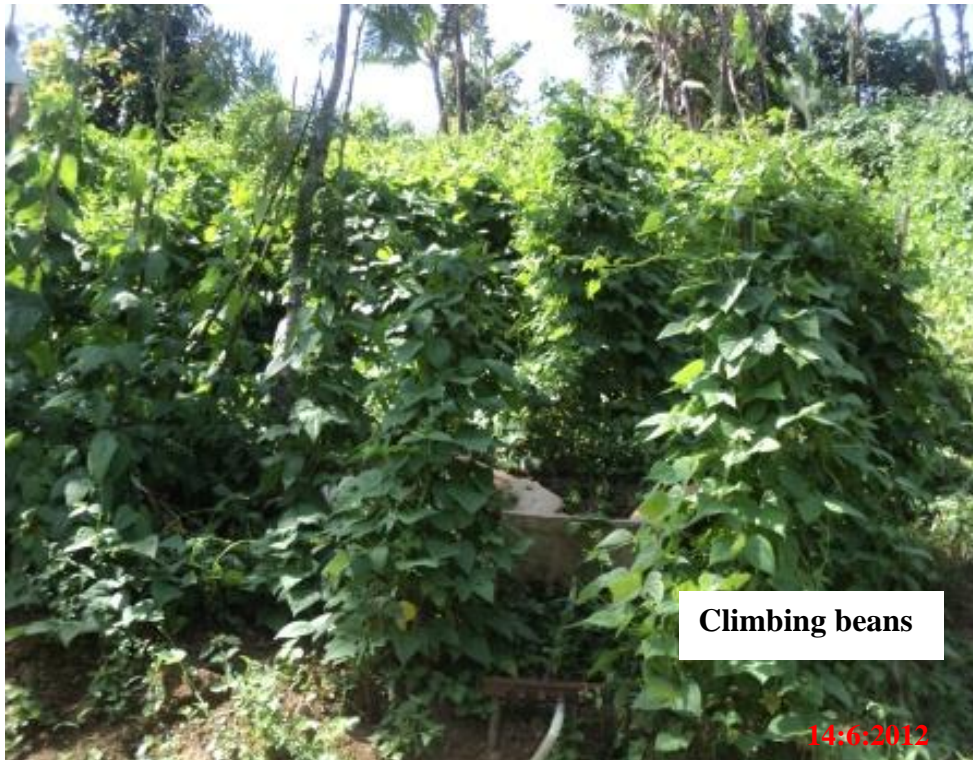
The observed variation in soil loss for climbing beans and bush beans during the study period can be attributed to the surface cover characteristics where by climbing beans had greater surface cover over bush beans during the growing period and also climbing beans grow upright with a lot of vegetation over bush beans (Plate 4.1, 4.2 and 4.3).



**Plate 4.1: Three weeks old climbing beans and bush beans plots**  
Source: Author (2013)



**Plate 4.2: Ten weeks old climbing beans and bush beans**  
Source: Author (2013)



**Plate 4.3: Twelve weeks old climbing beans**

Source: Author (2013)

However, surface cover monitoring for these different bean types was not conducted but different authors (Sperling and Muyaneza, 1995; Buruchara, 2007; and PABRA, 2007) have concluded the same on surface cover and growth characteristics. So it is on this basis that the study's explanation of reduced soil loss in climbing beans is closely related to these characteristics. This is in agreement with Mulebeke (2004) observations in Lake Victoria basin where soil surface cover influenced soil loss from the different land uses. In a plot scale level study by Gimeno-García *et al.* (2007) in Valencia, a conclusion was reached that surface cover influences soil loss. Ouyang *et al.* (2010) also noted that vegetation status has a significant impact on sediment formation and transport.

Climbing beans controlled soil loss more than bush beans; this is due to the low runoff registered by the climbing beans as a result of high surface cover (Plate 4.3) which intercepts rainfall, diminishing its energy and offering better protection to the soils. This is in line with studies by Bagoora (1998); and Bamutaze (2011) which show that high runoff rate translates into high soil loss. Though during this study, there was no ground cover monitoring, other studies from different authors (Buruchara, 2007; and PABRA, 2007) explain that climbing beans have surface cover which stays longer (200 days) before maturity over bush beans. Durán *et al.* (2011) study in the coastal areas of Granada and Malaga indicated that *Lavandula dentata* which contributed the highest surface cover reduced soil loss more as compared to the other plant cover types and similar conclusions were noted by Zhou *et al.* (2008). Therefore, soil surface cover is a function of land use management and erosion control.

#### **4.4.2 Nitrogen (N), Phosphorus (P) and Potassium (K) losses**

This sub-section was a follow up of objective two where by the macro-nutrients (NPK) vital for the plant growth were assessed and analyzed from the runoff and sediments during the study period for the two bean types.

Results indicated that annual total N and P loss in water from runoff were significantly different ( $P < .05$ ) except total K between climbing nsbeaand bush beans. Bush beans contributed the highest annual total N, P and K losses, 0.09, 2.09 and 0.37 Kg ha<sup>-1</sup> yr<sup>-1</sup> as compared to climbing beans, 0.003, 0.32 and 0.24 Kg ha<sup>-1</sup> yr<sup>-1</sup>, respectively (Table 4.1).

**Table 4.1: Runoff nutrient losses from climbing beans and bush beans**

Bean type	Nutrient loss (Kgha <sup>-1</sup> )								
	Long rain season			Short rain season			Annual		
	TN	TP	TK	TN	TP	TK	TN	TP	TK
Climbing beans	0.01	0.41	0.56	Trace	0.20	Trace	Trace	0.32	0.24
Bush beans	0.19	2.65	0.91	0.02	1.56	0.02	0.09	2.09	0.37
LSD <sub>0.05</sub>	0.15	0.95	0.53	0.03	0.55	0.03	0.07	0.51	0.20

During long rains season (season one), total N and total P were highly significantly different ( $P < 0.05$ ). Bush beans lost the highest nutrients through runoff of 0.19 N Kg ha<sup>-1</sup> yr<sup>-1</sup>, 2.65 P Kg ha<sup>-1</sup> yr<sup>-1</sup> and 0.91 K Kg ha<sup>-1</sup> yr<sup>-1</sup> as compared to climbing beans, 0.01 N Kg ha<sup>-1</sup> yr<sup>-1</sup>, 0.41 P Kg ha<sup>-1</sup> yr<sup>-1</sup>, 0.56 K Kg ha<sup>-1</sup> yr<sup>-1</sup> (Table 4.1). In short rain season (season two), total P was highly significant  $P < 0.05$  between the two types of beans; with bush beans contributing to the highest total P loss, 1.56 Kg ha<sup>-1</sup> yr<sup>-1</sup> than climbing beans, 0.2 Kg ha<sup>-1</sup> yr<sup>-1</sup>. Total N and K were not significantly ( $P > 0.05$ ) different between the two types of beans, however, there were statistical differences in the means of these nutrients between the types of beans. Bush beans had the greatest amount of nutrients lost (0.02 N Kg ha<sup>-1</sup> yr<sup>-1</sup> and 0.02 K Kg ha<sup>-1</sup> yr<sup>-1</sup>) than climbing beans which registered trace amounts (Table 4.1).

Results for nutrient losses along with sediments showed that annual nutrient losses varied between the two bean types. Total nitrogen varied significantly ( $P < 0.05$ ) between bush beans and climbing beans. Total phosphorus and Potassium loss did not vary significantly at  $P < 0.05$  between the two bean types, however, their means varied statistically (Table 4.2). The highest total N, P and K losses were observed from bush beans; 1.87, 0.6, and 0.12 Kg ha<sup>-1</sup> yr<sup>-1</sup> as compared to the climbing beans, 0.49, 0.10, and 0.03 Kg ha<sup>-1</sup> yr<sup>-1</sup>, respectively.

**Table 4.2: Soil nutrient losses from climbing beans and bush beans**

Bean type	Nutrient loss $\text{Kgha}^{-1}$								
	Long rain season			Short rain season			Annual		
	TN	TP	TK	TN	TP	TK	TN	TP	TK
Climbing beans	0.57	0.03	0.06	0.43	0.05	Trace	0.49	0.10	0.03
Bush beans	1.48	0.07	0.22	2.17	0.95	0.02	1.87	0.60	0.12
LSD <sub>0.05</sub>	1.03	0.04	0.18	0.79	1.03	0.02	0.62	0.68	0.11

Seasonal nutrient losses through soil detachment varied across bean types (Table 4.2). Total soil N and P loss were highly significant ( $P < .05$ ) between bean types during Long rain season (season one). Bush beans registered the highest nutrient losses than climbing beans during season one (Table 4.2). Likewise, in short rain season (season two), total N and P lost were significantly different ( $P < .05$ ). Just like for season one, bush beans recorded the highest amount of nutrient loss during season two, however, nutrient loss along with soil loss was generally higher during season two especially for bush beans (Table 4.2).

The higher nutrient loss through runoff and sediment from bush beans as compared to climbing beans could be attributed to several causes. Since bush beans experienced the highest runoff and soil loss in its season, it likewise lost corresponding amounts of nutrients than climbing beans since nutrients were tested from eroded soils. This pattern is in agreement with the work of Kizza (2012); Silgram *et al.* (2010); Zhang *et al.* (2004) and Khan (2001). The lower vegetation cover under bush beans compared to climbing beans according to Sperling and Muyaneza, (1995) caused higher nutrient losses from bush beans. This conforms to Centeri (2002) observations in Tihany Peninsula who reported that higher vegetation cover registered low nutrient losses. Durán *et al.* (2011); and Kothiyari *et al.* (2004) studies indicate that increase in vegetation cover, reduce nutrient losses.

N, P and K are essential for plant growth, therefore their loss from runoff and soil are very detrimental to the agricultural production in terms of soil fertility loss in the catchment as well as the water resources degradation; and particularly N nutrient can cause eutrophication if continuously eroded down the streams. Therefore, management options have to be drawn to reduce runoff and soil loss which influences nutrient loss especially when bush beans are cultivated in the catchment.

#### **4.4.2 Hypothesis test that the annual amount of soil and nutrient loss through erosion is not significantly different between the bean types**

This hypothesis was tested using the F-test by establishing the differences between the individual means of soil loss from bush beans and climbing beans at 5 % L.S.D. The results showed that mean annual soil loss was significantly different ( $p= 0.035$ , d.f =1) between climbing beans and bush beans (Appendix II) hence rejecting the null hypothesis and accepting the alternative hypothesis which stipulates that the annual amount of soil loss through erosion is significantly different between the bean types.

In addition, nutrient (NPK) losses from runoff and sediments were also tested using F-test to check if they are not significantly different between the bean types. For nutrient losses from runoff, N and P losses showed significance difference ( $p<.001$ ;  $p= 0.023$ , d.f =1) between the bean types receptively (Appendix II) hence rejecting the null hypothesis however, K losses through runoff were not significantly different ( $p= 0.08$ , d.f =1) between the bean types hence accepting the null hypothesis. For the nutrient losses along with sediments, total nitrogen varied significantly ( $P = 0.011$ , d.f=1) between bush and climbing beans (Appendix II) hence rejecting the null hypothesis for this nutrient while total phosphorus and potassium losses did not vary significantly

( $p > 0.05$ ) between the two bean types hence accepting the hypothesis for these particular nutrients (Appendix II). Therefore, climbing beans have significant control of soil and nitrogen losses down the catchment than bush beans. This helps to protect the water streams in the catchment hence reducing on water pollution in the catchment with time.

#### **4.5 Objective 3: Effects of climbing bush beans on selected soil physical and chemical properties**

This objective was achieved through assessing the effects of both bean types on soil structure expressed as Mean Weight Diameter (MWD) and Soil Organic Carbon (SOC), available Phosphorus (P), exchangeable Potassium (K) and Sodium (Na), Calcium (Ca), Magnesium (Mg) and soil pH at both 0-15 cm and 15 - 30 cm depths during before planting and at harvest for each season at the mid slope landscape position. The following subsections provide the results and discussions for the different properties.

##### **4.5.1 Effect of climbing and bush beans cultivation on soil structure**

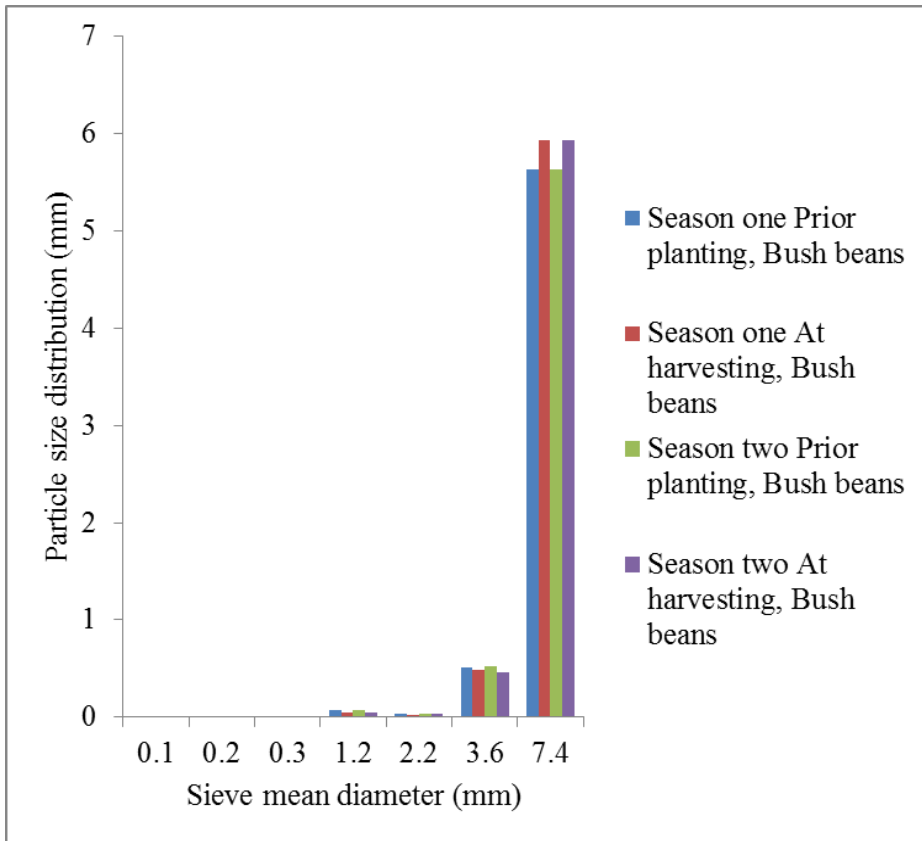
The effect of climbing beans and bush beans on soil structure at the middle landscape position before planting and after planting was assessed in the laboratory and analyzed statistically using one way Analysis of Variance at 5 % LS.D. Results showed that aggregate size distribution expressed as Mean Weight Diameter was not significantly different ( $p > 0.05$ ) across the bean types, sampling periods and seasons. However, Mean Weight Diameter (MWD) increased from prior to planting to harvesting following the two rainfall seasons (Table 4.3).

**Table 4.3: Changes in aggregate size (MWD) under bush and climbing bean types across two seasons**

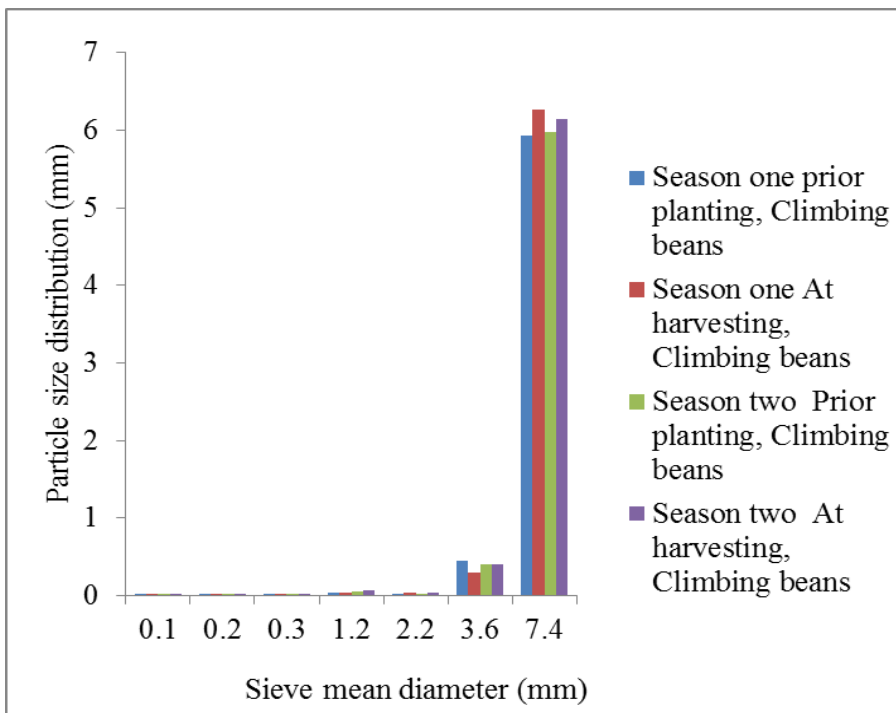
Bean type	Long rain season		Rel. MWD %	Short rain season		Rel. MWD %
	MWD (mm)			MWD (mm)		
	Prior planting	At harvesting		Prior planting	At harvesting	
Bush beans	6.44	6.65	3.3	6.45	6.64	2.9
Climbing beans	6.25	6.49	3.8	6.27	6.47	3.2

*MWD = Mean Weight Diameter and Rel. MWD % = Percentage Relative Mean Weight Diameter*

There was increase in soil structure for bush beans prior to planting to harvesting for both seasons (Table 4.3). This was evident with increase in particle size distribution in relation to the sieve mean diameter (Figure 4.8) and similar pattern occurred in climbing beans (Figure 4.9). Therefore, bush and climbing beans improved soil structure after the two rainfall seasons. This is due to the fact that legumes are rich in the protein, glomalin, and the symbiotic association along the roots of legumes and other plants, both serve as a “glue” that binds soil together into stable aggregates (Finlay, 2008) and also these legumes have aggressive taproots reaching 6 to 8 feet deep (Kalyebara, 2004) that open pathways deep into the soil; and the nitrogen they possess encourages earthworms which increase soil porosity, promoting air movement hence improving soil structure (Finlay, 2008).



**Figure 4.8: Particle size distribution in bush beans for each season**



**Figure 4.9: Particle size distribution in climbing beans for each season**

The highest soil structure increase was recorded during the long rains (season one) as compared to short rains (season two), (Table 4.3); and climbing beans registered the greatest soil structure increase in both seasons as compared to bush beans (Table 4.3).

This variation in soil structure improvement between the two types of beans could be attributed to the differential surface cover of these bean types which in turn influences rain drop energy impact on the soil. LaI (1991) also observed that surface cover management influence changes in soil structure stability. Hermawan and Bomke (1997) also observed that increased surface cover due to cover crops improved stability due to increase in soil organic carbon.

Climbing and bush beans all recorded increments in the MWD during the period of before planting up to harvesting of 3.8 % and 3.3 % and 3.2 % and 2.9 % for season one and two, respectively (Table 4.3). The level of soil structure aggregation from these two types of beans is attributed to their canopy cover, growth and root characteristics. However, climbing beans registered the highest relative change in Mean Weight Diameter than bush beans. According to Wortmann et al. (1998) explains that green canopy cover takes longer (about 6 weeks) in climbing beans before flowering as compared to bush beans which retain their green cover for up to 2 – 3 weeks before flowering. Climbing beans also grow as high as 2 metres than bush beans; 30 cm tall (Buruchara *et al.*, 2007) hence the effect of raindrop energy on the soil surface to disintegrate the soil particles is reduced more in climbing beans than in bush beans. This is in agreement with studies reported by Gardner and Gerrard, (2003); and Kwaad *et al.*, (1998) who concluded that vegetation cover stabilizes soil aggregates. In addition, according to Gicharu (2011), climbing beans have extensive root systems which bind the soil particles hence improving the soil structure.

Climbing beans have a longer maturity period of 200 days (Graham, 1997) attributing to increased SOC; which improves soil structure due to the binding effects of organic matter as compared to bush beans which take shorter maturity period. This is in agreement with Márcio dos Reis *et al.* (2008) who found out that soil aggregate stability was improved under maize monocrop as compared to other crop types due to increased total organic carbon.

#### **4.5.2 Effect of climbing and bush beans cultivation soil chemical properties**

The effect of climbing beans and bush beans on selected soil chemical properties was assessed and analyzed in the laboratory to examine the effect of cultivating the two bean types on soil chemical properties at 0-15 cm and 15-30 cm depths during the two rainfall seasons. The properties reported in this subsection include nitrogen, Soil organic carbon, available phosphorus, exchangeable potassium, calcium, magnesium, exchangeable sodium and soil pH.

From the results, at the soil surface (0–15 cm), chemical properties except soil pH, SOC and available P differed significantly ( $P < .05$ ) between the bean types (Table 4.4); soil nitrogen significantly differed ( $P < .05$ , % CV = 10.1) between bush and climbing beans at both pre-planting and harvesting.

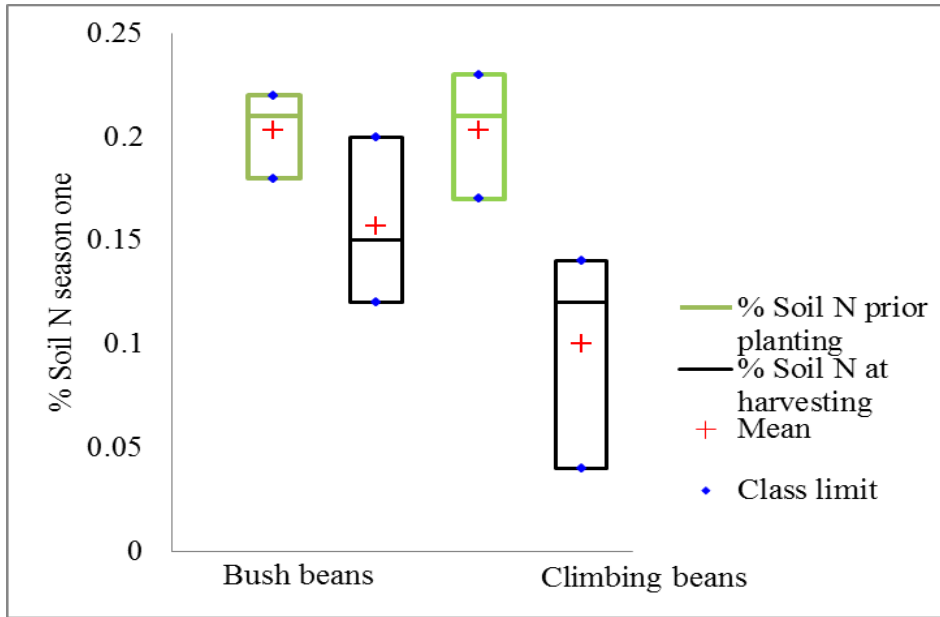
**Table 4.4: Effects of bush beans and climbing beans cultivation on selected soil (0-15 cm) physical and chemical properties**

Sampling period	Bean type	pH	N %	SOC	AV. P mgkg <sup>-1</sup>	K Cmoles/100g	Ca	Mg	Na
Pre-planting	Bush	5.0 <sup>a</sup>	0.20 <sup>c</sup>	1.9 <sup>a</sup>	2.6 <sup>a</sup>	0.39 <sup>a</sup>	3.23 <sup>a</sup>	2.11 <sup>ab</sup>	0.00 <sup>a</sup>
	Climbing	5.2 <sup>b</sup>	0.20 <sup>c</sup>	1.8 <sup>a</sup>	5.4 <sup>a</sup>	0.68 <sup>b</sup>	3.74 <sup>a</sup>	2.27 <sup>b</sup>	0.03 <sup>b</sup>
At harvesting	Bush	5.3 <sup>bc</sup>	0.16 <sup>b</sup>	2.3 <sup>b</sup>	14.2 <sup>b</sup>	0.60 <sup>b</sup>	5.13 <sup>b</sup>	2.35 <sup>b</sup>	0.10 <sup>d</sup>
	Climbing	5.4 <sup>cd</sup>	0.10 <sup>a</sup>	2.7 <sup>ab</sup>	22.3 <sup>b</sup>	0.56 <sup>ab</sup>	4.80 <sup>b</sup>	1.81 <sup>a</sup>	0.06 <sup>c</sup>
<i>LSD</i>		0.14	0.02	0.5	12.4	0.2	0.6	0.32	0.02
% CV		2.7	10.1	23.6	69.1	37	14.4	15.3	45.7

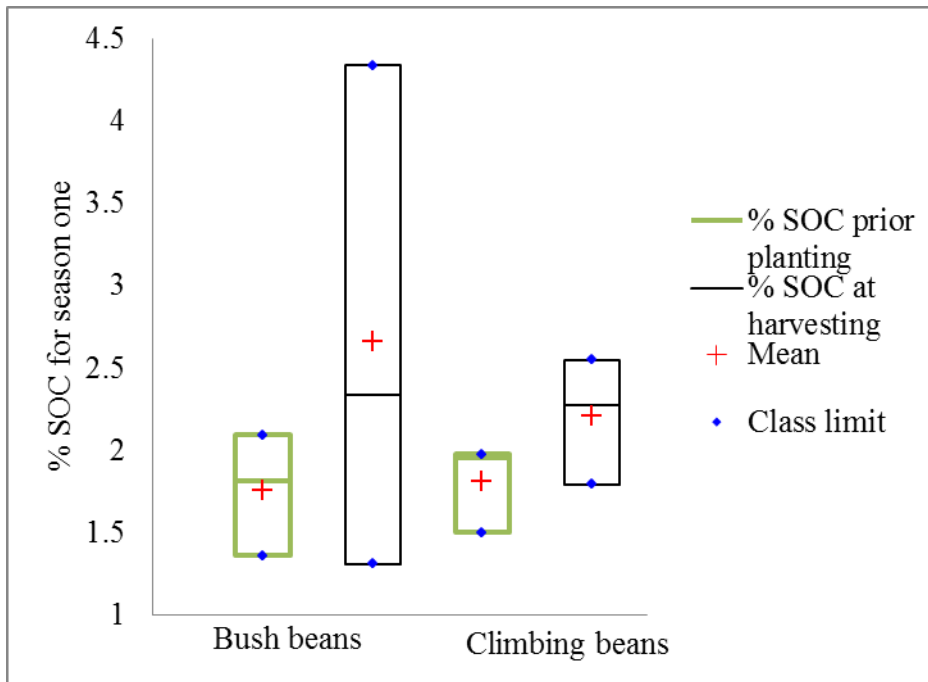
*Values followed by same letters in a column are not significantly different at  $P < .05$*

*Key: N- Nitrogen; SOC- Soil Organic Carbon; Av.P- Available Phosphorus; K- Potassium, Ca- Calcium; Mg- Magnesium; Na- Sodium*

At harvesting, the mean nitrogen content of bush beans (0.16 %) was higher than that of climbing beans (0.1 %), (Figure 4.10); and Soil Organic Carbon (2.7 % SOC) evolution was highest from the climbing beans contributing to 0.9 % SOC, 50 % to the initial SOC over bush beans (2.3 % SOC) with a contribution of 0.4 % SOC, 21 % to the initial SOC though the differences were not significant ( $P > .05$ , % CV = 23.6) between these bean types (Figure 4.11).



**Figure 4.10: Percent (%) soil N at 0-15 cm depth**



**Figure 4.11: Percent (%) soil organic carbon at 0- 15 cm depth**

Soil exchangeable potassium was not significantly different ( $P > .05$ , % CV = 37) between bean types, however, it was statistically higher from bush beans (0.6 Cmoles/100g) than from the climbing beans (0.56 Cmoles/100g) (Table 4.4).

Available phosphorus from both bean types drastically increased from pre-planting to harvesting though it was statistically lower from bush beans than from climbing beans (Table 4.4); and calcium and magnesium were statistically higher from bush beans than climbing beans. Exchangeable sodium (Na) content was significant ( $P < .05$ , % CV = 45.7) between the two beans types. However, the mean value of exchangeable sodium content from bush beans (0.10 Cmoles/100g) was statistically higher than that from climbing beans (0.06 Cmoles/100g) (Table 4.4). Considering the sub soil (15-30 cm depth), soil chemical properties were not significantly different ( $P > .05$ ) between bean types except total N and SOC (Table 4.5).

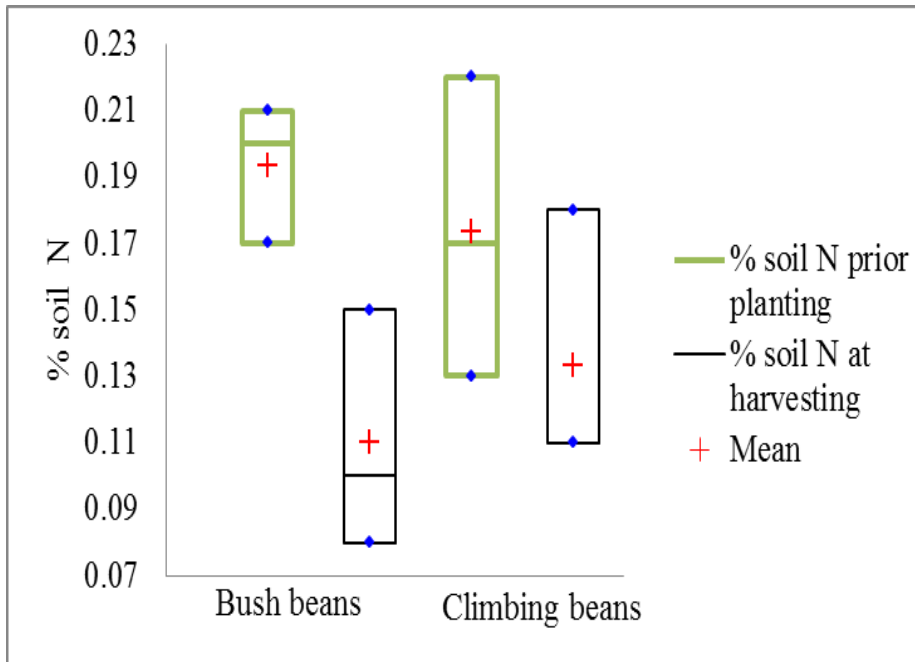
**Table 4.5: Effects of bush and climber beans cultivation on selected soil (15-30 cm) physical and chemical properties at pre-planting and at harvesting**

Sampling period	Bean type	pH	N %	SOC	AV. P mgkg <sup>-1</sup>	K cmoles/100g	Ca	Mg	Na
Pre-planting	Bush	5.0 <sup>a</sup>	0.19 <sup>d</sup>	1.8 <sup>a</sup>	2.2 <sup>a</sup>	0.35 <sup>a</sup>	3.1 <sup>a</sup>	2.0 <sup>a</sup>	0.00 <sup>a</sup>
	Climbing	5.4 <sup>b</sup>	0.17 <sup>c</sup>	1.8 <sup>a</sup>	4.6 <sup>a</sup>	0.56 <sup>b</sup>	3.5 <sup>b</sup>	2.2 <sup>a</sup>	0.01 <sup>a</sup>
At harvesting	Bush	5.0 <sup>ac</sup>	0.11 <sup>a</sup>	1.5 <sup>a</sup>	16 <sup>b</sup>	0.49 <sup>bc</sup>	4.3 <sup>c</sup>	1.8 <sup>b</sup>	0.10 <sup>b</sup>
	Climbing	5.1 <sup>ac</sup>	0.13 <sup>b</sup>	2.2 <sup>ab</sup>	29 <sup>c</sup>	0.57 <sup>bc</sup>	4.4 <sup>cd</sup>	1.8 <sup>b</sup>	0.09 <sup>bc</sup>
<i>LSD</i>		0.2	0.01	0.2	7.6	0.15	0.3	0.2	0.01
% CV		4.1	7.6	20.2	61.4	31.4	8.8	9.9	21.6

*Values followed by same letters in a column are not significantly different at  $P < 0.05$*

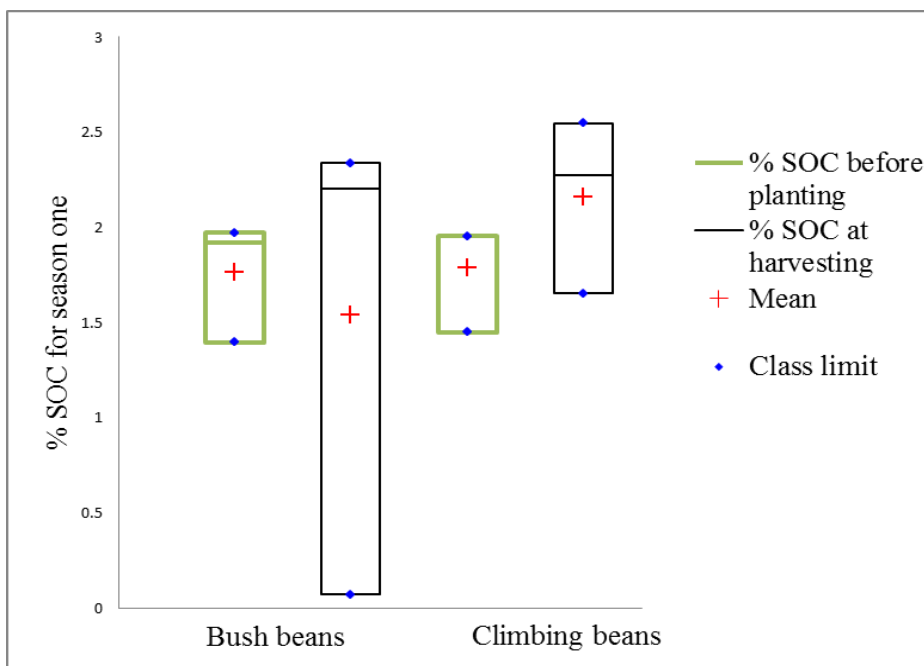
*Key: N- Nitrogen; SOC- Soil Organic Carbon; Av.P- Available Phosphorus; K- Potassium, Ca- Calcium; Mg- Magnesium; Na- Sodium*

There was a decline in the nitrogen content from both bean types; however, the decline was higher from bush beans (0.08 % N loss, 42 % loss to initial soil N) than from the climbing beans with 0.04 % N loss, 24 % loss to the initial soil N (Figure 4.12).



**Figure 4.12: Percent (%) Soil N at 15 -30 cm depth**

SOC differed significantly ( $P < .05$ , % CV = 20.2) between bean types (Table 4.5); climbing beans contributed the highest SOC (2.2 % SOC) statistically than bush beans (1.5 % SOC) (Figure 4.13).



**Figure 4.13: Percent (%) soil organic carbon at 15 -30 cm depth**

Bush beans had higher soil nitrogen (0.16 %) at the top soil. This could be due to their flowering characteristics though the study did not monitor it but different authors (Wortmann *et al.*, 1998; Allen and Edje, 1990) have explained that bush beans' flowering occurs at a shorter period (28-42 days) after planting hence NPK uptake is lower as compared to climbing beans which extend their flowering to 15 – 30 days due to the extra nodes formed after the initial flowering. In addition, according to Graham (1997), seed filling period takes few days (23 days) in bush beans while for climbing beans it may extend to 50 days; therefore, the nitrogen uptake and other nutrients are low in bush beans than climbing beans. The high yielding potential of climbing beans of about two to four times the yield of bush beans can also be a factor which attributes to the low nutrient content among the climbing bean types than bush beans (Katungi *et al.*, 2009).

SOC accumulation was higher in climbing beans (2.7 % and 2.2 %) at the top (0-15 cm) and sub (15-30 cm) soils respectively. This was due to the reduced runoff ( $36 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ ) and soil loss ( $121 \text{ Kgha}^{-1} \text{ yr}^{-1}$ ) and the more extensive roots (Gicharu, 2011) which led to more improved soil structure over bush beans. This is in agreement with Kaihura *et al.* (1998) observations in Tanzania who noted that total organic carbon loss was minimized due to reduced runoff and erosion. In addition, studies reported by Jankauskas *et al.* (2007); and Nadeu *et al.* (2012) confirm the same pattern. Soil ground cover in climbing beans was higher, increasing crop biomass as compared to the bush beans hence increasing the soil organic carbon. This conforms to Bationo *et al.* (2006) who reported that increased crop biomass increased SOC. In addition, Ruiz-Colmenero *et al.* (2013) observed that vegetation cover increased SOC by 1.2 % due to reduced erosion. The increased SOC in climbing beans clearly demonstrates

the high potential of climbing beans over bush beans in improving degraded watersheds.

#### **4.5.3 Hypothesis test that SOC content from climbing beans is not significantly different to that under bush beans**

This hypothesis was tested using the F-test tool by separating the individuals SOC means of the bean types at LSD (5 %). The results showed that SOC content from climbing and bush beans at 0-15 cm depth was not significantly different ( $p > 0.05$ ) hence accepting the null hypothesis (Appendix III) whereas at 15-30 cm soil depth, there was a significant difference at  $p < .05$  between the bean types after the two seasons hence rejecting the null hypothesis. Therefore, climbing beans at this depth are significantly different in terms of SOC content contribution with bush beans. (Appendix III).

## **CHAPTER 5: SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS**

### **5.1 Introduction**

This chapter provides the summary of findings; conclusions, recommendations and areas of further research from the results achieved during the study. The details are provided in the following subsections of this chapter as follows:

### **5.2 Summary of findings**

#### **5.2.1 Objective 1: Effects of climbing and bush beans' cultivation on runoff generation**

Annual runoff generation was significantly different ( $p < 0.05$ ) between climbing and bush beans. The annual runoff generation was higher from bush beans ( $248 \text{ m}^3\text{ha}^{-1}\text{yr}^{-1}$ ) than climbing beans ( $36 \text{ m}^3\text{ha}^{-1}\text{yr}^{-1}$ ). The highest mean annual runoff was generated from the low slope gradient site ( $379$  and  $48 \text{ m}^3\text{ha}^{-1}\text{yr}^{-1}$  for bush and climbing beans, respectively), than on the steep slope gradient site ( $137$  and  $18 \text{ m}^3\text{ha}^{-1} \text{ yr}^{-1}$  for bush and climbing beans, respectively). The percentage rainfall that ended up as runoff ranged between  $3.6 \%$  -  $21.9 \%$ ; and bush beans recorded the highest runoff coefficient ( $21.9 \%$ ) annually. The null hypothesis tested was rejected hence accepting the alternative hypothesis which stipulates that climbing beans are significantly better than bush beans in reducing runoff generation down the catchment.

### **5.2.2 Objective 2: Soil and nutrient losses from climbing and bush beans' cultivation**

Annual soil loss from the two bean types varied from 121 Kg ha<sup>-1</sup> yr<sup>-1</sup> for climbing beans to 548 Kg ha<sup>-1</sup> yr<sup>-1</sup> for bush beans; and there was significant difference ( $p < 0.05$ ) between the bean types during the study period. The null hypothesis tested was rejected hence accepting the alternative hypothesis which states that the annual soil loss through erosion is significantly different between climbing and bush beans.

The annual total N and P loss through runoff were significantly different except total K between climbing beans and bush beans at  $P < .05$ ; and bush beans contributed the highest annual total N, P and K losses; 0.09, 2.09 and 0.37 Kg ha<sup>-1</sup> yr<sup>-1</sup> in relation to climbing beans, 0.003, 0.32 and 0.24 Kg ha<sup>-1</sup> yr<sup>-1</sup>, respectively.

Annual nutrient losses along with sediment varied between the two bean types. Total nitrogen varied significantly ( $P < .05$ ) between bush and climbing beans. The highest total N, P and K losses were observed from bush beans; 1.87, 0.6, and 0.12 Kg ha<sup>-1</sup> yr<sup>-1</sup> as compared to the climbing beans; 0.49, 0.10, and 0.03 Kg ha<sup>-1</sup> yr<sup>-1</sup>, respectively.

The null hypothesis test for Nitrogen and Phosphorus losses along with runoff and nitrogen loss along with sediment was rejected while the null hypothesis for Potassium loss from both runoff and sediment with Phosphorus loss from sediment between the bean types was accepted.

### **5.2.3 Objective 3: Effects of climbing and bush beans cultivation on soil physical and chemical properties**

Aggregate size distribution expressed as mean weight diameter, MWD was not significantly different ( $p > 0.05$ ) across the bean types, sampling periods and seasons. However, MWD increased from pre-planting to harvesting for the two bean growing seasons. The highest soil structure improvement rate was recorded from climbing beans (3.8 % and 3.2 % for season one and two respectively) than bush beans (3.3 % and 2.9 % for season one and two, respectively).

Soil nitrogen for the depths (0-15 cm and 15-30 cm) differed significantly ( $P < .05$ ) between bush beans and climbing beans at both pre-planting and harvesting. At harvesting, the mean nitrogen content of bush beans (0.16 %, 0-15 cm) was higher than that of climbing beans 0.1 % for the same depth. However, at 15 -30 cm depth, there was a decline in the N content (0.08 % N loss, 42 % loss to initial soil N, bush beans) and (0.04 % N loss, 24 % loss to the initial soil N, climbing beans).

Climbing beans contributed to more SOC (0.9 % SOC, 50 % to the initial SOC) than bush beans (0.4 % SOC, 21 % to the initial SOC) annually at 0 -15 cm soil depth however, there was a decrease at the sub soils (15 -30 cm depth) for bush beans and an increase for climbing beans. The null hypothesis test that SOC content cropped to climbing beans is not significantly different to that under bush beans at 0-15 cm was accepted while at 15-30 cm, the null hypothesis was rejected.

## 5.4 Conclusions

Generally, the study revealed that there were low runoff, soil and nutrient losses in both climbing beans and bush beans grown in SW Uganda as compared to the stipulated threshold of  $10 \text{ tonha}^{-1}\text{yr}^{-1}$ .

Climbing beans are more efficient to bush beans in controlling runoff down the catchment. Bush beans recorded the highest percentage rainfall that ended up as runoff during the study period.

Climbing beans reduced soil and nutrient losses more than bush beans during the study period in the catchment. Therefore, growing climbing beans has an added advantage of soil and water conservation as an integrated watershed management practice to reduce on watershed degradation apart from being a food security crop in the area due to its more grain yielding.

Both climbing and bush beans did not contribute much to changes in soil structure though climbing beans led to a greater soil structure improvement over bush beans. However, climbing beans improved total SOC at both soil depths than bush beans. There was a high net decrease in soil N in climbing beans than in bush beans at the end of the two seasons.

The implication of the findings of this study is that climbing beans are environmentally beneficial in terms of soil and water conservation as part of the integrated watershed management approach especially at the mid slope landscape position in the highland areas where climbing beans and bush beans are intensively cultivated and act as food security crops. However, climbing beans contribute to a

high negative nutrient balance especially nitrogen as compared to bush beans since they are heavy feeders and take long to maturity.

### **5.5 Recommendations**

From the findings for objective one and two, it is recommend that in the study area, climbing beans should be promoted by Bufundi local government, Soil and water conservation activists, NGOs and farmers at the mid slope position or above bush beans in order to have a double benefit of increased yield and reduction of runoff, soil and nutrients loss over time down the catchment streams; which in the long run can sustainable watershed management. However, if bush beans are to be planted at this mid slope position or above the climbing beans, then integrated watershed management practices for soil and water conservation like grass bands, sugar cane plants which provide multiple benefits, elephant grass across the terraces, “fanya chini” and “fanya juu” should be adopted by farmers through the local governments by making by-laws and implemented in the catchment to reduce on runoff using the integrated watershed management tool which brings in different interested and affected stakeholders together (Policy makers, researchers, NGOs and government).

From the finding of objective three, it is recommended that supplementary nitrogen through application of biological nitrogen fixing inoculants known as rhizobia strain for beans and organic manure fertilizers which are cheaper should be encouraged to farmers by local leaders, local government, NGOs and researchers. This can be achieved by subsidizing inputs and ensuring market linkages and availability to farmers whenever they are planting climbing and bush beans. This will motivate famers to sustainably manage the watershed since the economic and social aspects are

looked into. Also prior to harvest, the climbing beans should be left to drop most of the leaves and the crop residues in the gardens to enhance soil organic carbon and nutrient recycling in order to reduce on the net negative nutrient balance.

## **5.6 Areas for further research**

For the purpose of comparability, the study can be replicated in Bufundi sub-catchment at a larger scale to comprehensively argue the environmental benefits of climbing beans over bush beans. Further studies on the environmental benefits of climbing beans *visa viz* bush beans while looking at leaching, rainfall intensity and bulk density from these bean types. Potential areas for research and development in the catchment include:

1. Assessment of environmental and social economic benefits of climbing beans and bush beans cultivation in SW Uganda.
2. Analysis of water quality from the different sources and sanitation status within the sub catchment.
3. Assessment of multipurpose tree species for soil and water conservation in the sub catchment.
4. Assessment of nitrogen leaching from climbing and bush beans

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**APPENDIX I: HYPOTHESIS TEST FOR RUNOFF AND BEAN TYPES**

Source of variation	d.f.	s.s.	m.s	v.r.	F pr.	
Bean type	1	940379.	940379.	19.51	<.001**	Hypothesis rejected
Season	1	284300.	284300.	5.90	0.018**	

*Figures followed by \*\* are significantly different at  $p < 0.05$*

**APPENDIX II: HYPOTHESIS TEST FOR SOIL AND NUTRIENT LOSSES FROM CLIMBING AND BUSH BEANS**

	Degrees of freedom(df)	Sums of square (ss)	Mean square (mss)	sums of Variance (Vr.)	Fpr
Soil loss	1	3835956	3835956	4.66	0.035**
<b>Nutrients loss along with runoff loss</b>					
N	1	40.06	40.06	19.93	<.001**
P	1	0.02	0.02	6.45	0.023**
K	1	0.24	0.24	3.27	0.08 <sup>NS</sup>
<b>Nutrients loss along with sediment loss</b>					
N	1	0.16	0.16	6.86	0.011**
P	1	65.45	65.45	49.28	<.001**
K	1	0.33	0.33	1.52	0.222 <sup>NS</sup>

*Figures followed by \*\* are significantly different at 5 % L.S.D hence hypothesis rejected and Ns means not significant hence hypothesis accepted*

**APPENDIX III: HYPOTHESIS TESTING FOR SOC AND BEAN TYPES**

Source of variation	Depth (cm)	d.f	s.s.	m.s.	v.r.	Fpr.	
Climbing and bush beans	0-15	1	0.00198	0.00198	0.06	0.803	Hypothesis accepted
	15-30	1	2.7671	2.7671	5.58	0.025	Hypothesis rejected