VALUING SOIL CONSERVATION BENEFITS OF AGROFORESTRY PRACTICES IN GATSIBO DISTRICT, EASTERN RWANDA

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THESIS SUBMITTED IN FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENVIRONMENTAL STUDIES OF THE OPEN UNIVERSITY OF TANZANIA

2017

CERTIFICATION

The undersigned certifies that he has read and hereby recommends for acceptance by the Open University of Tanzania a thesis entitled **"*Valuing Soil Conservation Benefits of Agroforestry Practices in Gatsibo District, Eastern Rwanda*",** in fulfillment of the requirements for the degree of Master of Environmental Studies (MES) of the Open University of Tanzania.

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Dr. Josephat Alexander Saria

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Date

DEDICATION

This work is devoted to my respected parents Twahirwa Celestine and Murekatete Bernadette and my beloved wife Mumararungu Peruth for their love, care and encouragement.

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ABSTRACT

The study was carried out in Kiramuruzi, Gasange and Kabarore Sectors of Gatsibo District in Rwanda with the aim of valuing the soil conservation benefits of agroforestry practices Reconnaissance survey, direct observation, key informant interview, questionnaire survey with schedule, and group discussion were used for primary data collection where purposive and random sampling were used. Gender and age groups were selected as sample household for interview. Secondary data were gathered from District Forest Office, NGOs, libraries, journals and magazines. Descriptive statistics was carried out and the results were summarized in graphs and tables. The results showed that land was found to be scarce mainly due to population pressure. However, the majority of farmers' own land that ranged from 1 to 3 ha where fodder trees were found to be the most common which was 94.4%, 85.4% and 81.25% of respondents from Kiramuruzi, Kabarore and Gasange sectors respectively, followed by fruit trees (94.4%, 82.9% and 81.25%) and timber trees (50%, 51.2% and 67.8%). The most common tree species were *Calliandra spp*. *Eupatrium spp, Saccharum spp, Imperata sppl, Cedrela spp, Grevillea r Leucaena spp, Mimosa spp, Moringa spp and Alnus spp.* In conclusion, agroforestry provides all types of forest products needs of households and is appropriate for the control erosion, to maintain soil fertility, and efficient nutrient cycling, vegetative cover and the improved animal diversity.

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LIST OF ABBREVIATIONS

AF	Agroforestry
CTFT	Centre Technique Forestiere Tropicale
EPIC	Erosion- Productivity Impact Calculator
HH	Household
FAO	Food and Agricultural Organization
GEMS	Global Environmental Monitoring System
ICRAF	International Centre for Research in Agroforestry
NISR	National Institute of Statistics of Rwanda
RNRA	Rwanda Natural Resources Authority
REMA	Rwanda Environment Management Authority
UNEP	United Nations Environment Program
USAID	United States Agency for International Development

CHAPTER ONE

INTRODUCTION

1.1 Background to Research Problem

Agro forestry can be defined as a land use system in which trees or shrubs are grown in association with agricultural crops, pasture or livestock (Young, 1989). Lundgren and Raintree, (1982) define agroforestry practices as an entire range of land use systems in which woody perennials are deliberately combined with agricultural crops and/or animals in some spatial or temporal arrangement. There are both ecological and economic interactions between the trees and other components. Study has shown that soil conservation is one of its primary benefits (Young, 1989).

The presence of woody perennials in agroforestry Practices may determine several bio-physical and bio-chemical processes that determine the health of the soil substrate (Nair, 1989). The adoption of agroforestry practices is considerably complex because it requires establishing a new input- output mix of annuals, perennials, green manure, fodder and other components combined with new conservation techniques such as contour hedgerows, alley cropping and enriched fallows (Sanchez, 1976). Unlike standard agriculture, there are fewpackaged agroforestry or farm based natural resource management practices to deliver to farmers (Sanchez, 1976).

Agroforestry is an ancient practice in the world where farmers deliberately retain and integrate trees into their farmland. It was widely promoted as a sustainability-enhancing practice combining the benefits of both forestry and agriculture (Bene,*et* *al.*, 1977). Agroforestry development has taken place in sub- Saharan African as a response to the major problems, including food shortage in many parts of the developing world, the increasing ecological degradation and the energy crisis at the beginning of the 1970s (Young, 1989).

Though agroforestry is a native practice in sub- Saharan rural communities, the formal research in the discipline started much later. Worldwide agroforestry research spear headed by ICRAF (International Centre for Research in Agroforestry) was firstly directed towards the description and characterization of the farmers' agroforestry practices (Sanchez, 1987) with the objective of identifying major constraints and opportunities for designing of adequate solutions.

Later, specific practices including intercropping and integrated farming systems were widely investigated to mainly deal with soil fertility and livestock concerns in the tropics. Agroforestry systems were developed with specific tree species such as Faidherbia albida that has shown great potential in providing fodder, the ability to fix nitrogen and other services (FAO, 1984).

In Rwanda, integrating fruit and legumes species within cropping systems was extensively tested using species such as avocado, mango, leuceana, calliandra calothyrsus and markdamia lutea in bean (Phaseolus vulgaris), potato (solanum tuberosum), pea (pisum sativum) and wheat (*triticum sp*.) (Nair 1989). Tree planting in Rwanda was limited to some plants around households such as *ficus thoningii, euphorbia tirucallii, erythrina abyssinica, vernonia amygdalina, dracaena* *afromontana*, etc., but the cultivation of woody perennials for timber, energy generation or other services was not part of the customs.

The first forest plantations were created in 1920 and 1948 and only consisted of *eucalyptus* species. Later on, other species were introduced (Fergus, 2013). These were namely *pinus sp., callistris sp., grevillea robusta, cedrella sp., cupressus sp*. Those plant species proved to be dangerous for the biological patrimony because they used to drain and acidify places that are already acid, causing the reduction or even the extermination of the underground biodiversity growth. The covered surface area was estimated at 256,300 hectares in 1998 (Nair 1989). Despite the efforts of diversifying tree species, it is estimated that 99% of trees consisted of Eucalyptus sp. However, a replacement of those trees by agroforestry species such as *grevillea sp., cedrella sp., maesopsis sp., calliandra sp., leucena sp.* proved to be of urgent need because of the added services they bring in agroecosystem (REMA, 2010).

The principle underlying the promotion of leafy biomass of agro forestry species lies in the fact that the addition of green manure is important in the tropics where most of the plant nutrients are provided from organic matter. The most remarkable effect of legume shrubs in livestock production was that related to the use of legume species such as Calliandra for milk production. Alongside these benefits, agro forestry could supply other basic services including firewood, food, medicine, fodder, timber, boundary markers and windbreaks (REMA, 2010).

Farmers design individual systems that respond to their multiple needs depending on the available resources, making the agro forestry systems complex in their arrangement over time and space. Several authors (Bucagu,*et al*,. 2013) have recognized that smallholder farmers in the tropics operate under diverse agro ecological conditions and within an agro-ecological zone, farm management is rarely homogenous. Other authors have stressed the importance of both socioeconomic and agro-ecological conditions in the identification of a window of opportunity that favors particular forms of management (Stoking, *et al*., 1988).

There is therefore, a need to use innovative approaches to identify potential contribution of agroforestry practice to soil and water conservation in Rwanda. The purpose of this research is to *value the soil conservation benefits of agroforestry practices in Gatsibo district, Eastern Rwanda* by exploring the existing agroforestry practices; assessing the impact of agroforestry on soil erosion control; assessing the impact of agroforestry to maintenance of soil fertility and by assessing the impact of agroforestry on farm productivity.

The analysis to be done in this research will be hopefully utilized to help decision-makers in the process of formulation and implementation of sustainable soil conservation in Rwanda with a particular emphasis on agroforestry.

1.2 Problem Statement

Farmers in Rwanda depend on forest products such as timber, poles, fuel wood, fodder, litter, compost, medicine, and fruits plants. Due to mounting pressure of exponential growth in human and livestock population, it has been subjected to various pressure and misuse resulting in degradation of land, loss of biodiversity and declining cultivable land. These have increased the gap between demand and supply for rural needs fulfillment. Today, the existing allocation to agriculture and forestry are inadequate to meet the demand for food, timber, fuel, fodder, and other minor products. This is the right time to exercise option to convert low productive and less exploitable land into a productive goal by adopting agroforestry for diversification and sustainable biomass production (REMA, 2010).

There are several practices in different agro-ecological region of Rwanda, but they are not well studied and documented. Now it is necessary to document, evaluate, improve and replicate the best practices in other parts of the country. Moreover, the agroforestry systems that have been traditionally practicing only return the subsistence need of the local people and from this subsistence return; the socio-economic status has not been uplifted. The present need is the commercial and semi-commercial return from their productions and the integrated farming system so that they can get maximum benefit from the limited resources (RNRA, 2012).

Agro forestry can respond to farmer's needs by protecting forest, making tree products such as firewood and fodder easily available to farmers, restoring fertility of land by decreasing soil erosion, adding nutrients through decomposition of leaf litter and nitrogen fixation, recycling leached-down nutrients and helping breakdown of nutrients in the subsoil by means of deep roots. Problems such as shortage of forest resources can be reduced by the mid hill farmers through retaining or keeping trees in various parts of their farmland along with crops for centuries despite having limited landholding (REMA, 2010).

This research intended to assess the benefits of agroforestry in meeting the needs of rural farmers through soil conservation. As the agroforestry technique encompass a wide variety of system and diverse array of crop, livestock, and trees species, this research attempted to find out the contribution in the conservation of precious natural resources and questions such as which are the existing agroforestry practices in Gatsibo District, what is the impact of agroforestry on soil erosion control in the study area what role does agroforestry play in maintenance of soil fertility; what is the impact of agroforestry on farm productivity in the study area were responded.

This research explored the existing agroforestry practices of farmers in private farmland areas for improving the agroforestry in Gatsibo District. The finding of the research would be directly beneficial to the practitioners as they get feedback from the research findings. The findings would also be useful to all Districts that fall in similar ecological zones to get idea for the adoption of new alternatives as agroforestry or improving the existing practices.

1.3 Objectives of the Research

1.3.1 General Objective

The general objective of the study is the assess the value of soil conservation benefits of agroforestry practices in Gatsibo District, Eastern Rwanda.

1.3.2 Specific Objectives of the Research

(i) To evaluate the present status of agroforestry practice in the study area.

(ii) To determine the impact of agroforestry on soil erosion control in the study area.

(iii) To examine the contribution of agroforestry in maintenance of soil fertility and soil productivity.

1.3.3 Questions of the Study

(i) What is the present status of agroforestry practice in the study area?

(ii) What is the impact of agroforestry on soil erosion control in the study area?

(iii) What role does agroforestry play in maintenance of soil fertility and soil productivity?

1.4 Purpose of the Research

Farmers in Rwanda depend on forest products such as timber, poles, fuel wood, fodder, litter, compost, medicine, and fruits plants. Land is a vital natural resource and is the basis of our existence. Due to mounting pressure of exponential growth in human and livestock population, it has been subjected to various pressure and misuse resulting in degradation of land, loss of biodiversity and declining cultivable land. These have increased the gap between demand and supply for rural needs fulfillment. Today, the existing allocation to agriculture and forestry are inadequate to meet the demand for food, timber, fuel, fodder, and other minor products. This is the right time to exercise option to convert low productive and less exploitable land into a productive goal by adopting agro forestry for diversification and sustainable biomass production.

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This research intended to assess the impact of agro forestry to meet the needs of rural farmers. As the agro forestry technique encompass a wide variety of system and diverse array of crop, livestock, and trees species, this research will be attempt to find out the contribution in the conservation of precious natural resources.

The research proposed to explore the existing agro forestry systems and practices of farmers in private farmland areas for improving the agroforestry in Gatsibo District. The finding of the research will be directly beneficial to the practitioners as they get feedback from the research findings. The findings will also be useful to all Districts that fall in similar ecological zones to get idea for the adoption of new alternatives as agroforestry or improving the existing practices.

1.5 Scope and Limitations

In order to attain a better understanding of the benefits of agro forestry in Rwanda, this study consisted of a broader analysis of the practice at national level. The main reason to include such an analysis was to provide a realistic overview of the current situation regarding the soil conservation sector. In addition, the research identified the main problems and driving forces for further improvement, where such measures for soil conservation can be implemented, such as selection of best and suitable trees species. The research scope focused on the agro forestry practice.

Regarding the relevant geographical boundaries, this study was limited to Gatsibo District located in Eastern Province of Rwanda based on the mounting pressure of exponential growth in human and livestock population in the area, which has been subjected to various pressure and misuse resulting in degradation of land, loss of biodiversity and declining cultivable land.

These have increased the gap between demand and supply for rural needs fulfillment. Today, the existing allocation to agriculture and forestry are inadequate to meet the demand for food, timber, fuel, fodder, and other minor products. This is the right time to exercise option to convert low productive and less exploitable land into a productive goal mine by adopting agroforestry for diversification and sustainable biomass production.

1.6 Dissertation Outline

This dissertation is organized into five major Chapters. Chapter one constitutes the introduction, which mainly focuses on the background, statements of the problem, objectives, purpose of the study. The second chapter deals with reviews of different literatures about agroforestry. The third chapter states the methodology used, comprising of the various stages adopted in the research study. This includes the research design, population, sample and sampling procedures, instruments and data collection procedures and data analysis. Chapter four contains presentation and discussion of the results and the last fifth chapter contains conclusion and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Role of agroforestry systems in soil conservation in a private land of hill area is biologically and socially more complex than other systems for using degraded lands either through fodder trees, fruit trees cultivation or forest farming (RNRA, 2012). A common hypothesis is strongly implied to the agroforestry systems that integration of variety of tree species with herbaceous crops increase the biodiversity and increase the overall productivity consumed by households, reduce soil loss and improve the physical and chemical properties of soil. There have been few attempts on this aspect.

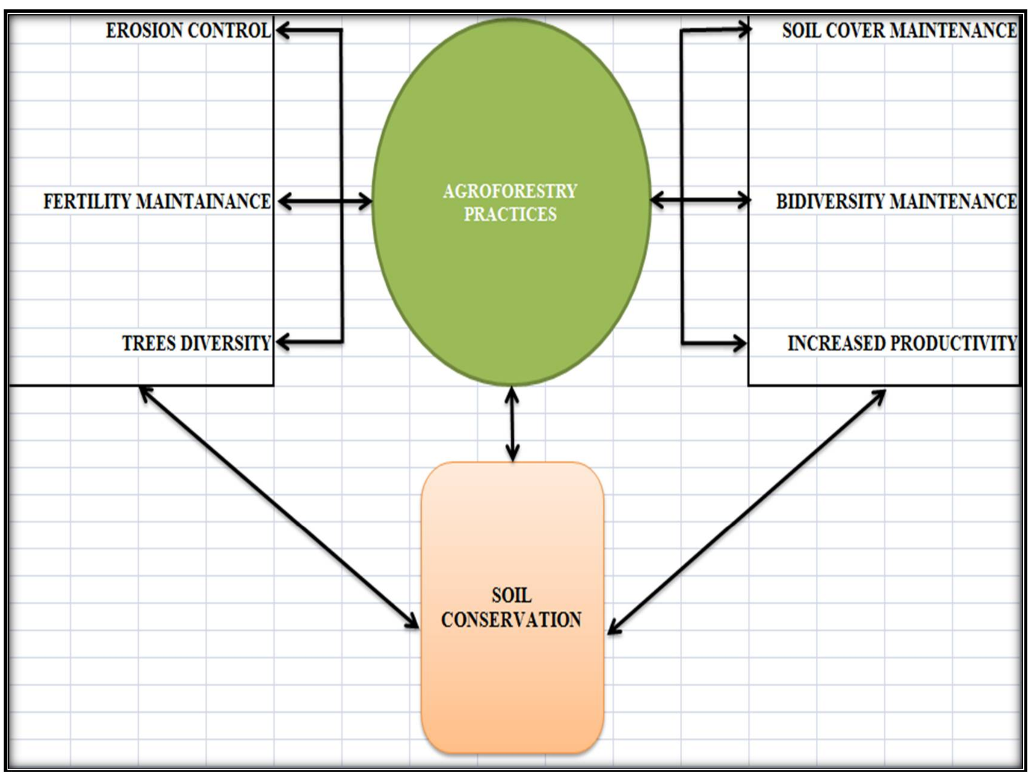

Figure 2.1: Conceptual Framework

However, literature reveals ample vacuum as regards to systematic studies on the role of agroforestry in soil conservation and consumption of agroforestry products by rural people of hill area. In this chapter, an attempt has been made to review the information available on these aspects of agroforestry systems as per the following conceptual framework.

2.2 Species Diversity and Agroforestry

Most often in natural or agricultural systems, species counts (species richness) are provided as the measure of diversity. Continuing this logic, diversification means adding more species. Species diversity, however, is a function of the number of species, and the evenness in distribution of species' abundances (Hobs,*et al.*, 1993). Options for diversification can therefore be dissociated into interventions that target richness and those that target evenness.

Human disturbance on natural ecosystems is the major threat to local biodiversity. A pool of species will eventually go locally extinct unless its habitat is repaired or restored. Human efforts to aid the degraded habitat restoration will increasingly become a crucial aspect of the conservation of biodiversity in forest ecosystems. The application of agroforestry as an integrated approach to biodiversity conservation on farms in support of nature reserves has received some attention (Atta-Krah, *et al.*, 2004).

In the realm of agroforestry, underpinning the need for diversification is the desire to enhance the stability and productivity of agro-ecosystems. It has been recommended that agroforestry can be seen as a tool in conjunction with appropriate conservation areas to buffer biodiversity loss, because agroforestry in some sites has 50 to 80% of the diversity of comparable natural forests and can help restrict the conversion of forests to grassland or other mono specific crops (Atta-Krah, *et al.*, 2004).

Studies (Ochola *et al.* 2010) that take into account the ability of plants to uptake and manage resources have strongly highlighted the importance of functional groups and functional diversity. A function group is defined as a set of species with similar impacts on ecosystem process (Hobbs,*et al.*, 1993). They are characterized by a set of common biological attributes that relate with their behavior. Related studies that link biodiversity and ecosystem function have been recognized as a way to improve our knowledge on the causal connections between biological variability and ecosystems. Even though attempts to study the impacts of agroforestry on environment have received attention, our knowledge on the causal mechanism sand approaches to evaluate the influence are poorly documented (Hobbs *et al.*, 1993).

2.3 Contribution of Agroforestry to Soil Conservation

Farmers have always grown trees on their land, some no doubt with as hrewd idea that this had useful effects on the soil and crop yields. In scientific publications, the first recognition that trees benefit soils came in accounts of the ecological stability of shifting cultivation, provided there was an adequate ratio of forest fallow to cropping (Greenland,*et al.*, 1977).

There were isolated instances of those whom, in retrospect, we can recognize were ahead of their time in appreciating the possibilities of integrating trees with farming systems. Thus Leakey, writing of highland Kenya in 1949, advocated rows of trees along contours to control the problem of soil erosion; whilst in 1950, Dijkman (1950) wrote of "*Leucaena*" a promising erosion-control plant. For many years, reclamation forestry has been practiced as a means of improving degraded land, notably in countries like India.

More widespread scientific recognition awaited the emergence of agroforestry as a scientific discipline from the late 1970s onwards (Young, 1989). Soils research in agroforestry, which drew upon experience from other kinds of land use and assessed its significance for agroforestry; and the review, Soil-productivity aspects of agroforestry (Nair, 1989), in which the main agroforestry systems, traditional and modern, were assessed with special reference to soil aspects. The latter forms a foundation for the present review.

Other accounts of soil conservation in agroforestry include surface erosion under various tropical agroforestry systems, tree crops as soil improvers in the humid tropics, agroforestry for soil conservation, increasing the productivity of smallholder farming systems by introduction of planted fallows, amelioration of soil by trees, ecological aspects of agroforestry with special emphasis on tree-soil interactions, soil productivity and sustainability in agroforestry systems (Sanchez,1987).

The above accounts have been freely drawn upon in the present review, which was published in draft form as three ICRAF Working Papers, covering respectively control of erosion, maintenance of fertility, and a computer model to predict both (Young and Saunders, 1987).

2.3.1 Soil Conservation and Sustainability

Soil conservation is interpreted here in its broader sense to include both control of erosion and maintenance of fertility. Two policy trends have contributed to this view. First, soil conservation was formerly equated with erosion control. This attitude is still to be found in places; it leads to planning measures and projects in which erosion is thought of in terms of loss of soil material, and its control is treated in isolation from other aspects of agricultural improvement. It is now recognized that the principal adverse effect of erosion is lowering of fertility, through removal of organic matter and nutrients in eroded sediment (Young, 1989).

The second trend is the recognition of forms of soil degradation other than erosion, the various kinds of physical, chemical and biological degradation sometimes grouped as decline in soil fertility. It is now recognized that there can be serious soil-degradation problems even in areas where erosion is not a problem, and that it is part of the task of soil conservation to address these.

This leads to the view that the primary objective of soil conservation is maintenance of fertility. To achieve this, control of erosion is one necessary, but by no means sufficient, condition. Equally important is maintenance of the physical, chemical and biological properties, including nutrient status, which together lead to soil fertility (Young, 1989).

A broader field is that of soil and water conservation, since reduction in water loss through runoff is an integral part of soil conservation. In turn, soil and water conservation form part of the wider aim of the conservation of natural resources, which covers also the conservation of other resources, including vegetation (forests, pastures) and wildlife (IRCAF, 1989).

Desertification is a term that has been widely misused. Properly applied, it refers to irreversible, or slowly reversible, reduction in the productive capacity of the environment in the semi-arid zone. The main symptom, and direct effect on productivity, is impoverishment of the vegetation (both total biomass and composition). Low biomass, however, is commonly caused by drought, and will recover by natural processes if there is no other form of degradation. It is where soil erosion has also become serious that the power of recovery of the plant cover is reduced, and the structure can be correctly referred to as desertification (Baumer, 1987).

Sustainability, as applied to land use, is a more general concept than either soil and water conservation or the conservation of natural resources as a whole, and has been variously defined. It is essential feature is the link between conservation and production. Sustainable land use is that which achieves production combined with conservation of the resources on which that production depends, thereby permitting the maintenance of productivity.

For a land-use system to be sustainable requires conservation not only of soil but of the whole range of resources on which production depends. Harvesting of forests must not exceed rates of growth, for example, and there are wider considerations such as that of land tenure. However, the most direct and primary requirement for sustainability is to maintain soil fertility (Young 1989).

Besides being obviously true for arable cultivation, this applies also to land-use systems based on grazing. Drought, or short periods of over-grazing, can lead to temporary degradation of pasture resources, but these may recover. The degradation becomes irreversible, and is thus correctly described by the term desertification, if over-grazing is allowed to continue to the point at which soil degradation sets in. (Dregne, 1987).

The objective of sustainable land use is the continuation of production over a long period that covered by the planning horizons of planners and farmers, usually about 20 years, occasionally up to 50. Given the current food shortage in the less-developed world, and the virtually inevitable population increase, the present call is for forms of land use that will not only allow maintenance of current levels of production, but will sustain production at higher levels than at present (ICRAF, 1989).

2.3.2 The Range of Agroforestry Practices

The existence of agroforestry is now widely recognized among planners and development agencies, it is not always appreciated how many different kinds of land-use practice are included within it. At the highest level, the classification is based on the components present: trees with crops, trees with pastures, practices in which the tree component is dominant and practices involving special components. The second level is based on the spatial and temporal arrangement of components. Rotational practices are those in which the association between trees and crops takes place primarily over time, whilst spatial practices are those in which it is primarily a combination in space. Spatial systems are divided into mixed and zoned (Young, 1989).

In mixed spatial practices, the trees and herbaceous plants are grown in intimate mixtures, with the trees distributed over more or less the whole of the land area. In zoned spatial practices, the trees are either planted in some systematic arrangement, such as rows, or are grown on some element in the farm, such as boundaries or soil conservation structures.

The third level of classification employs detailed spatial arrangement and functions as criteria. Considered as a basis for research, sylvo pastoral practices and those with special components are clearly distinct, requiring facilities for research into pasture and livestock or other specialized aspects. The remaining groups differ in the nature and extent of tree/crop or tree/pasture interactions. In purely rotational systems, the interaction takes place mainly through inheritance of soil changes. In spatial-mixed systems, the tree/crop interface is distributed over all or much of the land management unit, whereas in spatial-zoned systems it occupies defined locations (Young, 1989)

2.4 Role of Agroforestry in Soil Erosion Control

Evidence from direct experimental observations on erosion under agroforestry systems is limited. As in most branches of agroforestry research, however, there is much to be learnt from taking the results of research based on agricultural and forest land use and applying them to agroforestry. Awareness of the need for soil conservation arose in the United States of America (USA) in the 1930s. There had been many cases of irreversible soil loss by erosion before that time, perhaps as early as pre-classical times in the Mediterranean lands. Severe erosion occurred both in indigenous communities, as a result of increase in population and hence cultivation intensity, and following settlement of tropical lands by Western immigrants (Young, 1989).

Examples are chronicled in a milestone of erosion awareness, the rape of the earth. Examples are accounts of erosion in Nigeria, Trinidad and a review, soil erosion in the British colonial empire. Young (1997), remarked that soil erosion is “now one of the most serious problems in Africa”. As a consequence, soil conservation became part of the agricultural policy of the colonial powers, continuing as such through the 1950s. A notable example was Zimbabwe (then Southern Rhodesia) where conservation practices imported and adapted from the USA were widely applied (Young, 1997).

Whilst soil-conservation specialists never wavered in their advocacy, governmental awareness and policy emphasis declined in the 1960s. This coincided with the post-independence period in ex-colonial territories, where conservation was for a time associated with 'colonialist' policies and thus could not immediately be given a prominent place on the development agenda. Meanwhile, rising rates of population increase were leading to the frequent extension of cultivation onto steep slopes and other vulnerable land (FAO, 2010).

From the mid-1970s onwards, there has been a revival of awareness of soil conservation, and of attention to it in development policy. If any single factor can be held responsible, it is the continuing increase in pressure upon the land, the disappearance in most countries of substantial areas of new land for settlement and thus a growing appreciation of the dependence of production on land resources (Young, 1997).

A landmark was the formulation of the World Soil Charter by FAO (1982), coupled with increased emphasis on erosion control in FAO policy. More recently, the World Bank has given greater attention to environmental aspects of development. Adoption of conservation policies by government has naturally been variable but, as a generalization, it has increased over the past 10 years and is still growing. Looking to the future, a recent review of factors affecting land resources and their use over the next 50years lays much stress on the need to control soil degradation (Young and Saunders, 1987). The earlier or traditional approach, as practiced by soil-conservation or land-husbandry departments, is set out in standard texts and handbooks. Most textbooks were directed at US conditions, but that of Hudson (1983) is a clear summary, with a focus on the tropics, which has stood the test of time (Singh,*et al.*, 1981).

Changes to the earlier policy have come about through advances both in natural and social science. Recently, erosion is regarded as one of a number of forms of soil degradation, including deterioration of physical, chemical and biological properties, all of which require attention (FAO, 1979). Arising out of the need to justify conservation in economic terms, research effort has been directed at assessing the effects of erosion on soil properties and crop productivity. Specifically, it has been recognized that the consequences of erosion are by no means limited to loss of soil depth; its major adverse effects are loss of organic matter and plant nutrients, with consequent degradation of soil physical properties and decline in crop yields (FAO, 1979).

Experimental work has been carried out on the effects of erosion on crop yields. At first this was attempted mainly by means of artificial-desurfacing experiments. Later it was found that this method underestimated the yield reductions caused by erosion (Peake, 1986). There is a greater emphasis on the effects of soil cover as a means of controlling erosion, as compared with checking runoff. This arose in part out of experiments directed initially at the effects of mulching, and subsequently from work on minimum tillage (ICRAF, 1985).

It has become accepted that cultivation will continue on many areas of sloping land, and that ways must be found of making such use environmentally acceptable. Sloping lands, areas in which moderate and steep slopes are predominant, have become recognized as an identifiable type of environment with a set of distinctive problems (Siderius, 1986).

In extension, it is recognized that a prohibitive policy does not work, and conservation must be achieved through the willing cooperation of farmers. To do this, farmers must be motivated through being able to see benefits from conservation works. It follows that soil conservation should be introduced as part of an improved farming package, which will result in an immediate rise in crop yields or other benefits (ICRAF, 1985). In drier environments, there is greater integration between soil and water conservation. Conservation works are designed to achieve both.

Farmers may be led to adopt soil conservation if they can see that it leads at the same time to water conservation and thus improved yields. There is some recognition of the additional need to control erosion on grazing lands, although the amount of effort directed at this still falls short of its proportional importance (ICRAF, 1985).

The effects of agroforestry on soil-fertility maintenance should be considered jointly with direct effects on erosion control. Agroforestry has a potential for erosion control through the soil cover provided by tree canopy and litter, in addition to the role of trees in relation to the runoff-barrier function. The integration of conservation with improved farming in general, coupled with that of securing cooperation of the farmers at an early stage, accords well with the approach of agroforestry diagnosis and design (Raintree, 1987). In drier regions, erosion control should also be assessed jointly with the role of trees in water management.

Sylvopastoral systems should be included when assessing potential for erosion control. Seen from a broader perspective, the problem of soil erosion is socioeconomic as well as environmental and technical. Those who suffer most, the poorer farmers, are least able to undertake the conventional types of measures for its control (Roose, 1988). The low input costs of many agroforestry systems make them available to poorer farmers.

2.4.1 The Importance of Soil Cover

Besides the conclusion obtained above on the basis of predictive models, there is experimental evidence that soil loss can be greatly reduced by maintenance of a good ground surface cover. An experiment of great elegance was conceived many years ago, that of suspending fine wire gauze or mosquito netting a short distance above the soil surface. The netting breaks the impact of raindrops, which still reach the soil but as a fine spray (El-Swaify, *et al.*, 1984).

The soil is kept bare by weeding, and down slope runoff is allowed to continue unchecked. This artifice reduces erosion to about one hundredth of its value on unprotected bare soil. Evidence of the same kind comes from experimental work under agricultural conditions. Even a crop regarded as having a relatively high erosion risk, such as maize, substantially reduces erosion as compared with bare soil. A higher plant density and a better rate of growth give more cover and increased protection (Hudson, 1983). Erosion under cereals can be greatly reduced by intercropping with leguminous cover plants such as *Stylosanthes* or *Desmodium* (El-Swaify, *et al.*, 1984).

The contrast in protective cover between well and poorly managed crops is clearly seen in tea; a crop with close spacing, good growth and correct pruning provides a canopy cover of close to 100%, whereas poorly managed tea often leads to severe erosion; soil loss has been found to fall to low values where the canopy exceeds 65%. Mixed cropping provides better cover than monoculture. In oil palm plantations, erosion is prevented when the palms are young by a dense cover crop, often *Pueraria* sp. The nearly closed canopy of mature palms, however, shades them out. Erosion can be checked by placing pruned palm fronds on the ground, optimally with tips down slope to create inward flow towards the stems (Stocking, 1988).

Outside the tropics, the use of crop residues, a living vegetative cover and no-till have been found to be an effective way to control erosion in the south-eastern United

States; a 50% 'ground cover after planting' gives a cover factor (C) of 0.1; an 80% cover gives a factor of 0.05.A special case of mulching occurs under the minimum-tillage system. No-tillage alone, without barrier-type conservation works, reduces erosion to well within acceptable tolerance limits (ICRAF, 1985). A mulch cover does not need to be complete; a spatial cover of 60% or over can reduce erosion to a small fraction of its value without cover (Rose, 1988).

A notable practical example of cover control of erosion is reported from a moist sub-humid highland area in Tanzania. On an agricultural plot on a20-25° slope, erosion was kept to well below 1 t/ha/yr by cover-based management, including mulching with weeds and crop residues (Lundgren, 1980).

The relative effects of tree canopy, undergrowth and litter were compared in a study of a 5-year-old *Acacia auriculiformis* plantation under a low land humid climate in Java. These three elements were removed artificially, singly and in pairs. The tree canopy alone had relatively little effect and the added effect of undergrowth was small. Litter cover alone, however, reduced erosion by 95% as compared with bare soil. The situation of litter only cannot of course be maintained under natural conditions; decaying litter must be renewed by supply of fresh material from the canopy, which thus plays a role (Wiersum, 1985).

This evidence suggests that agroforestry systems are likely to be more effective in erosion control through supply of litter to the ground surface than through the effects of the tree canopy. Some multipurpose trees are deliberately chosen with a moderately open canopy to reduce shading effects. In spatially mixed agroforestry practices, such as home gardens, the multilayered plant structure may provide quite a dense canopy, but this is likely to be matched by the ground cover (Wiersum, 1985).

Evidence and induction therefore suggest that for erosion control, the greatest potential of agroforestry lies in its capacity to supply and maintain a ground cover. The direct effects of the tree canopy in providing cover are less than those of ground litter and a soil litter cover, maintained throughout the period of erosive rains, frequently reduces erosion to within acceptable levels, even without additional measures of the runoff-barrier type (Wiersum, 1985).

Thus the direct prevention of soil erosion is most effectively achieved by a cover of surface litter, consisting of crop residues, tree pruning or both. The role of the tree canopy is to provide a supply of leafy material, through direct litter fall or pruning, sufficient to maintain this surface cover (Siderius, 1986).

2.4.2 Agroforestry and the Use of Sloping Lands

It is recognized that sloping lands, meaning areas dominated by moderate and steep slopes, form a distinct and widespread type of tropical environment with special problems, foremost among which is erosion (Siderius, 1986). The introduction of agroforestry practices may provide a solution to the dilemma implied by the existence of a high erosion hazard under conventional arable farming on sloping land together with the fact that large areas of such land are already under arable use and must remain so. Certain practices, including barrier hedges, hedge row intercropping and multistorey tree gardens, have the potential to permitarable cropping on sloping land coupled with adequate soil conservation, leading to sustained productive use.

Current trials in Ntcheu District, Malawi, illustrate this situation (Atangana *et al*. 2013). Owing to population pressure, cultivation in this area has been widely and irrevocably extended onto land with slopes of 25° and over. A system of closely spaced barrier hedges is being tried with the specific aim of finding a way of making maize production sustainable on land which would conventionally have been classified as non-arable (Atangana *et al.* 2013).

It is neither desirable, nor practicable to introduce an additional class of land use, 'agroforestry', into land-capability classification (Sheng, 1986). The capacity of different agroforestry practices to achieve erosion control varies so widely that no limiting values of slope could be set for agroforestry as a whole. Capability classification is in any case becoming less widely favored, and no useful purpose would be served by adapting it for agroforestry. Land evaluation, on the other hand, is well adapted to the circumstances of the introduction of agroforestry practices into existing land-use systems. Any specific agroforestry practice, together with details such as tree and crop species and density, can be taken as a land utilization type, and its suitability on a number of given areas of land assessed (Atangana *et al*. 2013).

Details of them inner of assessment fall outside the scope of the present review, but the relevant point is that such assessment will include the potential for erosion control. By this means, it is possible to assess the suitability of existing land-use systems, and compare them with alternative forms of improved land use, both agroforestry and non-agroforestry. The design stage of agroforestry diagnosis and design is very compatible with the approach of matching in land evaluation (Young, 1989).

A question of great importance from the point of view of policy and investment is: 'in which areas are the potential benefits from agroforestry the greatest?' Since funds for research and development are limited, it is clearly desirable to know which areas should have priority. Much work still needs to be done on this question, but one feature relevant to the present discussion is clear: that among the areas regarded as having a high potential for agroforestry, sloping lands are notably common. This is illustrated by areas for which ICRAF has participated in collaborative or advisory projects (ICRAF, 1989).

Out of the first eight areas in the original collaborative program, two could be classified as moderately sloping and five contained much steeply sloping land. This experience is being continued, for example in recent cooperative work in Rwanda, Ethiopia, Nepal and Malawi. Whilst this is no evidence of a statistically provable nature, there can be no doubt that, of various broad sets of environmental conditions that of sloping lands is one of the highest in its potential for agroforestry (Young, 1989).

2.5 Agroforestry and Soil Productivity

Only in recent years has sufficient attention been directed towards the basic question of the effect of erosion on crop yields and soil productivity. Soil conservation was formerly justified on the more general grounds of preventing the complete loss of the natural resource of soil, thereby putting gland out of production. This is a valid long-term view, but does not satisfy the requirements of economic analysis. To justify soil-conservation measures in economic terms, it is necessary to show that erosion reduces land productivity. Most of the earlier research on this subject was based on the United States, and it is only since 1980 that substantial attention has been directed towards erosion and productivity on tropical soils (ICRAF, 1987).

The significance of this question for agroforestry lies not in any specific technical potentialities of agroforestry, but in establishing the basic importance of soil conservation from a social and economic point of view. Aid and investment have to be justified on the grounds of maintaining food production and providing an economic return on investment. If research into agroforestry is to be justified on the grounds of its potential to control erosion, then the approximate consequences of unchecked erosion must be known. Hence a brief summary of the current state of knowledge is given here.

This is based mainly on recent review papers as follows (Peake, 1986). The first attempts to relate productivity to erosion were based on loss of soil depth. Assume that a soil is 1 m deep, that it becomes uncultivable when the depth falls below 20 cm, and that erosion is at the quite severe rate of 60 t/ha/yr, equivalent to 4 mm of soil thickness. Productivity will then be reduced to zero in 800/4 or 200 years. The simplest assumption made was that the decrease in productivity with depth was linear, so that in the example given, crop yields would fall by 1/200 or 0.5% per year (Young, 1989).

Not surprisingly, analysis based on such reasoning showed that investment in conservation could rarely be justified in economic terms, other than on initially shallow soils. An advance was to estimate the effects of loss of topsoil not merely on depth but on other soil properties. In regions subject to drought or dry spells, reduction in depth is likely to lead to significant loss of the soil's water-holding capacity. A more sophisticated model has recently been developed, the Erosion-Productivity Impact Calculator (EPIC). This is of considerable complexity, taking into consideration many variables of weather, hydrology and soil; in particular, it calculates the cycling of carbon, nitrogen and phosphorus. The model has been successful in predicting sediment yields, soil changes and crop yields in the USA, and it is to be hoped that it will be tested for tropical conditions (Williams *et al.*, 1982).

In field studies, much early work was based on artificial desurfacing, the anual removal of a layer from the soil surface followed by growing of a crop on the soil that remained. A big step forward was made in the discovery that this method underestimated the reduction in crop yield by erosion. Comparison between soils with artificial desurfacing and plots subjected to high rates of natural erosion showed that for equivalent volumes of soil removed, yield decreases were far greater on the latter. In one instance, the yield decrease brought about by natural erosion was 16 times that caused by artificial removal of the same thickness of soil (Williams *et al.*, 1982).

The reason lies at least partly in the fact that eroded sediment contains a substantially higher content of organic matter and nutrients than that of the topsoil from which it is derived. The difference is called the enrichment factor in eroded sediment (ICRAF, 1987). Enrichment factors for carbon and the major nutrients are frequently in the range 2 to 4, and occasionally as high as 10, being higher on gentle slopes and for moderate as compared with rapid erosion (Stocking, 1986). Reasons may be that the uppermost few millimeters of soil are richer in organic matter and nutrients than the normally bulked for analysis and that erosion selectively removes nutrient-rich material; the relative importance of these factors is not known (ICRAF, 1987).

Tropical soils tend to suffer several times higher rates of crop-yield reduction than temperate soils on which there have been equivalent volumes of soil loss. In both the tropics and the temperate zone, yield decline is most rapid at first, that is, for the initial 10-20 cm of soil loss, after which the rate of yield reduction decreases exponentially. On ferric lixisols, the first10 mm (ca 140 t/ha) of erosion will cause a reduction in yield of the order of 75%; for further erosion, the reduction is slower. Yield decline is greatest on 'old' soils, that is, highly weathered tropical soils, in which there is a high concentration of organic matter in the topsoil. Another way of expressing this is that relative yield loss is greater on soils that are initially of lower fertility (Williams *et al.,* 1982).

These findings are all explicable if it is assumed that the major effect of erosion on crop yields is through loss of organic matter and associated nutrients, coupled with the nutrient enrichment effect. Tropical soils have a higher relative concentration of nutrients in the topsoil as compared with temperate soils, and this feature is greatest in the highly weathered soils of intrinsically low fertility. Once the relatively nutrient-rich topsoil is removed, further erosion of the same volume of soil will remove fewer nutrients (Stocking, 1986).

A schematic calculation illustrates the orders of magnitude involved. As an example of a widespread soil type of low inherent fertility, consider a plateau sanded soil.

Under natural vegetation, this is likely to contain about 0.1% of nitrogen in the top 15 cm. Assume a topsoil bulk density of 1.0 erosion at 10 t/ha/yr and a nitrogen-enrichment factor in the eroded sediment of 4.0. There will be a loss of 40 kg N/ha/yr, equivalent to removing two bags of fertilizer per hectare (Stocking, 1986).

This effect has been confirmed experimentally in Zimbabwe, in a five year experimental study of nutrient losses in runoff water and eroded sediment. Regressions between soil loss and nutrient losses showed that erosion of 30t/ha/yr causes a loss of about 50 kg nitrogen and 5 kg phosphorus per hectare, considerably greater than the amounts actually applied in fertilizer. The financial cost of replacing eroded nutrients varies fromUS$20 to 50 per hectare on arable lands and from US$10 to 80 per hectare on grazing lands (Stocking, 1986).

The apparent absence of yield decline on land in western countries believed to have suffered erosion may be because the addition of fertilizers can mask the effects. There is evidence of the same feature in the tropics; relative yield reduction is greater on unfertilized plots than on the same soil with added fertilizer. The 'solution' of counter acting the effects of erosion by adding fertilizer is, of course, not affordable to most farmers in less developed countries (Yost *et al*., 1985).

A second important influence on crop yields is that of soil physical conditions, made up of complex interacting properties, including structure, aggregate stability, porosity, bulk density, infiltration capacity and available water capacity. These properties are partly determined by the basic conditions of texture and iron minerals present, but are also substantially influenced by the variable factor of soil organic matter content. Lowering of organic matter normally leads to loss of porosity, decline in aggregate ability, increase in bulk density and lowering of infiltration capacity (Bichier, 2006).

These in turn cause substantial reduction in crop yield (Greenland *et al*, 1977). The concentration of organic matter in topsoil, coupled with the carbon enrichment ration in eroded sediment, means that erosion can substantially lower soil organic matter. Taking as an example a soil with 2% carbon content in 15 cm of topsoil, erosion of 50 t soil/ha/yr with a carbon enrichment ration of 2.0 will cause an annual loss of 2000 kg C/ha. Continued over five years, such erosion would reduce topsoil carbon by one third of its former value, leading to substantial degradation of physical properties.

Evidence of a different kind comes from a study of two sample areas in the Philippines in which farmers themselves were asked to assess the erosion problem on their land as 'very serious', 'less serious' or 'no erosion'. In all cases, yields were lower with very serious than with less serious erosion, 45-48% lower for the largest samples, the farmers reporting rice and maize yields. The third cause of reduced yields is not from erosion itself but from the increased runoff and reduced infiltration with which it is associated.

In humid regions this does not matter, since at the time of most rainfall the soil is at field capacity. In dry savanna and semi-arid regions, however, moisture stress is often the limiting factor upon crop yields (Siderius, 1986). The increased infiltration brought about by conservation measures can substantially increase the periods during which the soil profile is at or close to field capacity, thus reducing moisture stress. In the longer term, reduction in soil depth leads to lowering of available water capacity.

This not only reduces average crop yields but also increases the risk of crop failure through drought. This has been treated as the principal adverse effect of erosion in one analysis (Bichier, 2006). Erosion may adversely affect the growth and functioning of the trees themselves in agroforestry systems. In Hawaii, 'simulated erosion" (removalof 7.5-37.5 cm topsoil) greatly reduced nodulation, nitrogenous activity, nutrient uptake and growth of *Sesbania grandiflora* (El-Swaify *et al*, 1984).

Two conclusions emerge, the first relating to soil conservation in general,the second of specific relevance to agroforestry. First, recent work on there lations between erosion and productivity has confirmed and strengthened the view that loss of crop production through lowering of yields brought about by soil erosion is substantial. Given the fact that population pressure on land has led to more or less continuous arable cropping over wide areas, erosion is likely to be one cause of the low yields commonly occurring on such land.

Secondly, the main causes of yield reduction by erosion, in the short and medium terms, are lowering of fertility through loss of organic matter and associated nutrients, together with the effects of organic-matter losson soil physical properties. In dry regions, loss of soil moisture by runoff is a further important factor. Hence the problem of erosion control, in the sense of controlling the mass of soil removed, is closely linked to the problem of maintenance of fertility (Siderius, 1986).

2.5.1 Economic Analysis of soil Conservation

Given the strong competition for the use of investment funds, whether these originate from external aid or internal government revenue, it is difficult to implement soil-conservation measures unless they can be justified in economic terms. The alternative means of justification is to appeal to conservation of natural resources as desirable in its own right, or for the use of future generations; whilst a valid point of view, this is likely to carry less weight in making decisions on allocation of development funds (Dumsday and Flinn, 1977).

Cost-benefit analysis of soil conservation, whether on a private (farmer) or social (community) basis, is essentially a matter of comparing discounted net revenue with and without conservation measures. Both costs and benefits are likely to be affected. For a soil-conservation project of the conventional kind, such as bunds and waterways with mechanical construction, there will be a high initial capital cost, together with limited annual maintenance costs (zero if this is assumed to be done by farmer's labor in off-peak periods). This must be set against the difference in benefits, represented as crop yields at farm-gate prices; the simplest assumption is a constant yield with soil conservation, to be compared with a declining yield without. Specification of the expected crop yields, for the number of years taken as the basis of economic analysis, is essential (Bojo, 1986).

With the earlier approach to erosion-crop relations, based on soil depth, it was rarely possible to demonstrate acceptable benefit-cost ratios or internal rates of return, i.e. values comparable with the returns from investment in other forms of development. This remains true even at low rates of discounting. The decrease in yields on a soil-depth basis is too slow, or too far in the future, to have an appreciable effect on discounted benefits (Wiggins, 1981).

Where this was the case, there were two ways of attempting to justify conservation: by treating it as a special case economically, taking a long project life (e.g. 100 years or more) and a zero rate of discounting, or by regarding conservation as a prerequisite of other agricultural improvement sand not analyzing it as a separate element. This situation has been changed through recognition of the substantial crop-yield reductions brought about by nutrient losses through erosion. It has become possible to justify conservation projects in conventional economic terms (Dumsday and Flinn, 1977).

Instead of the eventual loss of production when soil depth is reduced below a minimum level, it is the rapid decline in yields in the initial years of unchecked erosion which is significant. A more direct approach is to estimate the losses of nutrients by erosion and to calculate the cost of replacing these as fertilizer. For the arable lands of Zimbabwe, and considering nitrogen and phosphorus losses only ,cost was estimated at $150 million a year (1984/85), which is three times the amount actually spent on fertilizers (Stocking, 1986).

Even if justifiable in terms of yield losses or fertilizer-replacement costs, problems remain in implementing conservation through physical works. When constructed by earth-moving machinery, the sheer cost makes large demands on capital. Construction by hand labor is possible, but farmers are rarely willing to do so since there is no perceived return from the high labour input. Another relevant aspect of economic analysis is that the costs of soil conservation increase in the order prevention < control < reclamation.

Least costly is to prevent serious erosion commencing on land initially in good condition; to control and reduce erosion where it is already occurring requires greater inputs and investment; most expensive is to reclaim and rehabilitate severely degraded land. On land already degraded, however, it may become possible to justify reclamation forestry in economic terms by combining it with production (ICRAF, 1987).

After an initial period of soil improvement under forest, the tree cover can be thinned and grass beneath cut for sale as fodder; positive benefit have been achieved for such a practice in India. With respect to economic analysis of conservation, conclusions of particular relevance to agroforestry are that the initial cost of establishing erosion-control works based on agroforestry, whether in terms of capital or labor, is frequently lower than that of terracing or bunds. The infrastructure costs of agroforestry, such as tree nurseries, are on a modest scale. In addition to the benefit from maintenance of crop yields through control of soil loss, some agroforestry practices may have the potential to lead to an increase in crop yields, above present levels.

In addition, there are benefits from the produce of the trees. Through either or both these effects, there can be an increase not only in actual benefits, but in those perceived by the farmer. On land already degraded, the cost of reclamation can be reduced if soil-improving trees are combined with controlled production (Dregne, 1987).

2.5.2 Agroforestry in Watershed Management

Some notable successes have been achieved through watershed planning and management, the integrated control of land use throughout a river catchment. The essence is to apply sound land-use planning to the whole of the catchment, with particular attention to erosion control and water management. Adequate mechanisms for control of land use and management practices are essential, combined with the cooperation of the land users (ICRAF, 1985).

To date, most such schemes have been based on judicious combinations of agriculture, erosion-control structures and protective forestry, the last particularly in steep first-order catchments and sometimes along riverbanks. There is considerable potential, but little experience, for including agroforestry among the range of land uses included in such planning (Sheng, 1986).

Sheng (1986) suggests that agroforestry should occupy sites intermediate in steepness between those for agriculture and forestry rests on too simplistic a notion of the range of practices. Conversely, it is unrealistic to think of covering an entire watershed with agroforestry practices! What is needed is to hold the various agroforestry options in mind when allotting land according to the principles of land-use planning (FAO, 1984).

2.6 Role Played by Agroforestry in Maintenance of Soil Fertility

We have stressed above that the major adverse effect of soil erosion is lowering of fertility, and that this is the main reason why measures should be taken for its control. The hazard of water erosion is at its most serious on sloping land, in virtually all climates, that of wind erosion on land of any slope in the semi-arid zone. In these two, very extensive, sets of environmental conditions, control of erosion is an essential step in maintaining oil fertility. It is, however, only one step (Dregne, 1987).

Land on which there is no substantial erosion hazard, level or nearly level land in the sub-humid and humid zones, is frequently subject to soil degradation or lowering of fertility, originating for the most part in what is loosely described as 'over-cultivation'. The potential of agroforestry to reduce or eliminate such lowering of soil fertility is at least as important as that of controlling erosion (Dregne, 1987).

In reality the two problems are not independent. Most land is liable to some degree of erosion and to other forms of soil degradation, both leading to lowering of fertility and loss of sustainability. On level ground, it is fortunate that one cause of fertility loss that of erosion, is absent. On sloping lands, water erosion is more likely to be the main cause of fertility loss, but most other forms of soil degradation will also be present. In this section, we are concerned with more general soil problems, applicable to lands that are subject to soil erosion but also to areas where there is no erosion hazard or where erosion has successfully been controlled (FAO, 2010).

2.6.1 Problems of Soil Degradation and Low Soil Fertility

The recognized forms of soil degradation are erosion, physical, chemical and biological degradation, sanitization and pollution, where chemical degradation includes both acidification and lowering of nutrient content. They are closely linked:

biological degradation influences both soil physical properties and nutrients, whilst erosion is a cause of both biological degradation and loss of nutrients. All these forms of degradation lead to lowering of soil fertility and land productivity. However, it is the combined effect of lowering of soil organic matter, deterioration of physical properties, lowering of nutrient content and (in some cases) acidification that is commonly referred to as decline in soil fertility (FAO, 1984).

A number of governments and international agencies have made estimates of the proportions of agricultural land suffering from 'slight, moderate and severe' soil degradation. Viewed as precise figures, they are of very dubious value, since no soil-survey organization has yet systematically applied objective methods of assessing soil degradation. Still less can we distinguish where fertility is still declining from where a condition of low level equilibrium has been reached. A start has been made in devising methods (FAO, 2010).

Degradation assessment is an aim of the Global Environmental Monitoring System (GEMS) of the United Nations Environment Program (UNEP), and attempts are being made to include it in the Soils and Terrain data base of the International Society of Soil Science. Be that as it may, there can be no doubt that over very large areas under rain fed agriculture in the tropics and subtropics, soil fertility is less than it was 10, 20 or 50 years ago (ICRAF, 1985).

Older farmers can be prompted to express this view. In the present context, it is appropriate to cite experience in applying the method of agroforestry diagnosis and design. Following the identification of distinctive land-use systems, this method is directed first at finding out the kind and severity of problems existing in these systems, and then at diagnosis of their causes. It has been applied, for example, within the All-India Coordinated Research Program in Agroforestry and the ICRAF Agroforestry Research Networks for Africa.

Decline in soil fertility, sometimes expressed as low crop yields, is one of the most frequent problems observed over a wide range of environments (Singh *et al*., 1981). Soil degradation not only lowers the crop yields obtainable on the basis of intrinsic soil fertility; it can also substantially reduce the response to fertilizers or other inputs.

This lowers the economic margin on fertilizer application, tending to perpetuate the situation of low inputs with low out puts. A partial exception to the above generalization is the case of swamp rice cultivation. On the one hand, this system contains natural mechanisms for maintenance of soil fertility; on the other, at least some use of manure sand fertilizers is now normal in many countries. There are certainly problems of decline in soil fertility, but these are of a distinctive nature (FAO, 1984).

The problem of inherently low soil fertility is distinct from that of degradation of formerly fertile soils. Population increase has led to many areas that were formerly under natural forest or pastures being taken into cultivation, the so-called 'marginal lands'. Among the most commonly encountered problems of low natural soil fertility are acidity, low nutrient content in general, deficiencies in specific nutrients, most commonly nitrogen and phosphorus and adverse physical properties (Sheng, 1986)

2.6.2 Management Options for Maintaining Soil Fertility

Some lands are newly settled, others have been farmed for hundreds or thousands of years. To maintain soil fertility, many modern and traditional methods including agroforestry have been practiced. For every method there are constraints which limit its applicability as a practical management option in less-developed countries. A constraint of type of land means that the practice is only applicable on land with certain properties.

This applies to use of naturally sustainable soils, and to flood irrigation and swamp rice cultivation (Young 1997). Naturally sustainable soils are those derived from basic rocks (nitisols) which have the capacity to renew fertility by weathering of rock minerals and can sustain early continuous cultivation; they are of limited extent, carry high population densities, and are now so intensively used that they are no longer free from degradation (Sheng, 1986).

Renewal of fertility by the nutrients carried in flood waters was a feature of some of the earliest forms of agriculture, now largely lost through flood control. Swamp rice cultivation possesses natural methods of fertility renewal, as well as responding well to inputs. It already supports about half the population of less-developed countries, largely in Asia, and is steadily being extended. Predominantly found on alluvial lands, it is unrealistic to suppose that the vast labor input needed to construct irrigated terraces, such as those of Java, the Philippines or Nepal, will be developed in other continents (FAO, 2010). The high productivity per unit area of land makes it certain that this will continue to be a valuable form of development, but one largely confined to valley floors and alluvial plains (ICRAF, 1987).

The constraint of extent of land most obviously affects the first practice listed, that of responding to declining crop yields by clearing and cultivating more land. It applies also to green manuring, a form of non-productive improved fallow which has rarely found favor with farmers. The technique of fallowing, or shifting cultivation, was formerly the most widespread means of restoring the fertility lost in cultivation. It is also the oldest agroforestry practice. Much has been written about shifting cultivation, the basic message being that it is sustainable provided that the fallow periods are of adequate length, but it tends to be soil degrading where fallows are shortened by pressure of population upon land (Sheng, 1986).

2.6.3 Agroforestry as a Practical Management Option

The more widely applicable is agroforestry, as a practical option in farm management, the more necessary it is to appraise its benefits and improve techniques. At an early stage in the modern awareness of agroforestry, it was said to be particularly suited to 'marginal' lands, those with environmental hazards such as drought, erosion or low soil fertility. If this were so, then the extent of its potential application would be substantially reduced, although large areas would still remain (Young, 1989).

Evidences from the ICRAF agroforestry systems inventory shows that this is not the case. Agroforestry systems are found in humid regions, on gently sloping land and on some of the most fertile soils, as well as in more difficult environments. For example, the Chagga home gardens system is found on relatively rich soils, whilst systems of intercropping and grazing under coconuts occur mainly on level, alluvial land, in both cases under plentiful rainfall (Nair, 1989). Current agroforestry research is found in fertile areas as well as marginal, for example on the Lilongwe Plain of Central Malawi, the richest agricultural area in the country. The reason for the early presumption was that land-use problems were generally most serious in marginal lands, and these were where help from agroforestry was first sought.

In the early years of the ICRAF Collaborative Program, steeply sloping environments were over-represented, and they are also common in the systems inventory. Certainly, there are some sets of environmental and social conditions in which the potential for agroforestry is particularly high: densely populated, steeply sloping lands are one such, frequently having problems of erosion, fertility decline, forest clearance and fuel wood shortage (Young, 1989).

For one major environment, that of alluvial plains, the potential of agroforestry is probably less than on erosion landforms, although research may prove this to be false. Several systems of combining trees with swam price cultivation are known (Young, 1987). Thus agroforestry is potentially applicable to a very wide range of types of land in the tropics. Different practices are applicable in different environments, for example, multipurpose windbreaks in semi-arid areas, or trees for soil conservation on sloping lands. Research into land evaluation for agroforestry is needed to identify those kinds of environment, which are particularly suited to specified agroforestry practices (Young, 1987).

Agroforestry is a highly practicable management option at the farm level. It requires neither substantial capital nor machinery, and the necessary skills for tending trees can be learnt by farmers with limited formal education. The main inputs required in agroforestry, additional to those in agriculture, are supplies of tree germplasm and seedlings. Whilst there may be temporary local shortages, there are no intrinsic supply constraints. Local tree nurseries are simple and relatively cheap to construct (ICRAF, 1987).

There is nothing in agroforestry development projects comparable to the level of expense involved in, say, construction of dams or roads. The supply constraint of fertilizers is likely to be reduced or unchanged. In present-day agroforestry development, the major costs are research and training. With respect to inputs and capital, therefore, agroforestry is a relatively undemanding form of development, with no serious supply constraints (FAO, 1984).

2.6.4 Trees as Producers of Biomass

Measured rates of net primary production under natural ecosystems can serve as a reference point for agroforestry in two ways. First, they indicate there lative biological productivity to be expected under different climates. Secondly, they would provide minimum values to be expected, if it could be assumed that under agroforestry the combined effects of species selection and management will achieve higher rates of biomass production (ICRAF, 1985). A summary of ranges and mean values is given in Table 19, the sources for which are compilations from primary data. The most representative value for rain forest is 20 000 kg/ha/yr (dry matter), ranging from half to over twice this value (ICRAF, 1985).

Nitrogen or phosphorus is most frequently the limiting nutrients in tropical soils. There is nearly always a substantial initial response to nitrogen fertilizer application.

Phosphorus deficiency commonly appears after a few years of cultivation, when initial soil supplies become depleted. Potassium is less commonly limiting, except under root crops. Sulphur deficiency appears locally, where it is deficient in soil parent material (ICRAF, 1985).

Deficiencies in micronutrients are most likely to appear where major nutrient shortages are remedied by fertilizers. In this respect, biological means of soil improvement have an inbuilt advantage, in that plant residues are likely to contain the small quantities of elements required. This could be a significant benefit from agroforestry (Young, 1989).

There is a fundamental distinction in kind between nitrogen, originating from atmospheric fixation, and the other nutrients, the original source of which is rock weathering. Since nutrients are necessarily removed in harvest, they must be replaced, and if not present in soil parent materials, no amount of recycling can make up what is not there. If nutrient reserves are present in weathering rock but only at depth, tree roots may be able to tap sources unavailable to crops (Young, 1997).

There is a second source in atmospheric deposition, in rain and dust, which may be substantial in relation to the low requirements of natural vegetation but is small in comparison with rates of removal in harvest. Thus in general, land-use systems with no artificial inputs can only be sustainable at low levels of output. It would be mistaken, however, to consider agroforestry as a means of maintaining fertility solely through biological means. Its potential would be greater if it could also be shown to increase the efficiency of use of fertilizers (Young, 1989).

2.7 Agroforestry in Rwanda

Agroforestry is an integrated approach of using the interactive benefits from combining trees and shrubs with crops and/or livestock. It combines agricultural and forestry technologies to create more diverse, productive, profitable, healthy and sustainable land-use systems. In agroforestry systems, trees or shrubs are intentionally used within agricultural systems, or non-timber forest products are cultured in forest settings. Knowledge, careful selection of species and good management of trees and crops are needed to optimize the production and positive effects within the system and to minimize negative competitive effects (REMA 2010).

Agroforestry systems can be advantageous over conventional agricultural and forest production methods through increased productivity, economic benefits, social outcomes and the ecological goods and services provided. Biodiversity in agroforestry systems is typically higher than in conventional agricultural systems.

Agroforestry also has the potential to help reduce climate change since trees take up and store carbon at a faster rate than crop plants. Alley cropping in radical terraces is a form of intercropping, and can be applied by farmers as a strategy to combat soil erosion, to increase the diversity of farmland, as a means for crop diversification and to derive other integrated benefits. In this practice, crops are planted in strips in the terraces between rows of trees and/or shrubs. The potential benefits of this design include the provision of shade, retention of soil moisture, and increased in the structural diversity of the site for wildlife habitat. The woody perennials in these systems can produce fruit, fuel wood, and fodder (REMA, 2010).

Farmers have practiced agroforestry for years. Agroforestry focuses on the wide range of working trees grown on farms and in rural landscapes. Among these are: trees for land regeneration, soil health and food security, fruit trees for nutrition, fodder trees that improve smallholder livestock production, timber and fuel wood trees for shelter and energy, medicinal trees to combat disease and trees that produce gums, resins or latex products (REMA, 2010).

In the era of global warming, fast degradation of land productivity and other environmental hazards, agroforestry is indeed a stake for natural resources and socio-economic sustainability. Agroforestry can be found to be the most desirable strategy for maintaining social, economic and ecological sustainability in Rwanda. Agroforestry can be considered more as an approach than as a single, finished technology. Although several finished systems have been devised and tested, such technology may require adjustment for particular situations. The flexibility of the agroforestry approach is one of its advantages (RNRA, 2012).

The impacts of the degradation of the environment on people's everyday lives are not the same for men and women. When the environment is degraded, women's day-to-day activities, such as fuel and water collection, require more time, leaving less time for productive activities. When water becomes scarce, women and children in rural areas must walk longer distances to find water, and in urban areas are required to wait in line for long hours at communal water points. Despite their efforts, women living in arid areas tend to be categorized among the poorest of the poor, and have absolutely no means to influence real change. They are often excluded from participating in land development and conservation projects, agricultural extension activities, and policies directly affecting their subsistence. Men make most decisions related to cattle and livestock, and even in households headed by women, men still intervene in the decision-making process through members of the extended family.

However, because of the important contribution of women, the fight against the degradation of arid areas requires a gender-inclusive approach (REMA, 2010). Land tenure influences how different groups use natural resources. Women, the poor, and other marginalized groups are less likely to invest time and resources or adopt environmentally sustainable farming practices on land they do not own. Women's food crops are relegated to rented, steeply sloped land with eroding soils. Because tenure is not secure, women have little incentive to invest in soil conservation measures (REMA, 2010).

Women do sometimes participate in watershed management, for example, by maintaining forest cover to reduce soil erosion which often floods and silts reservoirs and waterways. Training programs on the technical and scientific aspects of watershed development including soil and water conservation measures and techniques on wetland restoration must include women. Women need the necessary skills, knowledge and confidence to participate in community decision-making and to assume leadership roles in management of watershed development. Gender analysis is need for all components of most watershed development activities (REMA, 2010).

Women and men around the world play distinct roles in managing plants and animals, in use of forests, dry lands, wetlands and agriculture. Moreover, gender roles are differentiated in collecting water, fuel, and fodder for domestic use, and in generating income. Due to their distinctive engagements with the natural environment, women's experience and knowledge are critical for environmental management. Using a gender perspective and enabling the integration of women's knowledge of the environment will increase the chances of environmental sustainability (USAID, 2005).

2.7.1 Common Agroforestry Species in Rwanda

Following are the on common Agroforestry species used in Rwanda. These species are common in Rwanda and in accordance with technical production capacities such as the characteristics of soils, climate, and natural ecosystems (REMA 2012).

2.7.1.1 *Calliandra Calothyrsus*

Calliandra calothyrsus is a small, thornless, often multistemmed shrub. Under optimum conditions it can attain a height of 12 m and a trunk diameter of 30 cm, but its average height is 5-6 m and diameter 20 cm. A multipurpose species grown primarily for forage as a supplement to low quality roughages for ruminant livestock. *C. calothyrsus* can be used to rehabilitate erosion-prone areas and recover land exhausted by agriculture, where it easily dominates undesired weeds such as *Eupatrium spp.*, *Saccharum spp.*, and *Imperata cylindrica*. Roots are able to fix atmospheric nitrogen because of thesymbiosis with Rhizobium bacteria (to which root nodules bear witness) and the symbiosis with root fungus.

High leaf biomass production and high yields of protein leaf material on less fertile soils make it very suitable as a green manure and it is used in alley-cropping systems.

C. calothyrsus is compatible with crops, with both deep roots and extensive fibrous roots (FAO, 2010).

2.7.1.2 *Cedrela Serrata*

Cedrela serrata is a moderate-sized deciduous tree, in favourable situations attaining a height of 30 m and a girth of up to 3.3 m. The leaves and young shoots are lopped for cattle fodder. The wood is used for furniture, poles, and other uses and planted as a shade tree in tea plantations and also in coffee plantations (REMA, 2010).

2.7.1.3 *Grevielle Robusta*

Grevillea robusta is a deciduous medium-sized to large tree 12-25 (max. 40) m tall; crown conical, dense, with branches projecting upwards. The golden flowers are attractive to bees, making it an important honey plant. It is also used as shade tree in coffee and tea plantations. Its spreading branching system makes it ideal for windbreaks or shelterbelts against wind-induced mechanical damage, high rates of transpiration and surface evaporation. A deep rooting system causes little interference with shallow-rooted crops, and it can be successfully intercropped with banana, tomato and other agricultural crops (REMA, 2010).

2.7.1.4 *Leucaena Diversifolia*

Leucaena diversifolia is a tree or erect shrub, 3-20 m tall, with a single-stemmed bole 20-50 cm in diameter, slender and clear up to 10 m in height, ascending branches with horizontal twigs. Soil erosion can be controlled effectively by planting *L.diversifolia*. Its light crown makes *L. diversifolia* an ideal species for shade cover perennial crops such as coffee. It can be planted for soil amelioration and stabilization i.e. nitrogen fixing (REMA, 2010).

2.7.1.5 *Mimosa Scabrella*

Mimosa scabrella is a small- to medium-sized tree 4-12 (max. 20) m high, with a tall, straight, slender trunk 10-50 cm in diameter in forest, or short and branched, with dense rounded crown of grey foliage, or a large shrub. Abundant flowering make it excellent for honey production. Produces high-quality firewood; however, the charcoal produces a large amount of ash.

Shade or shelter: *M. scabrella* is used as a shade tree for highland coffee plantations. The tree is able to fix atmospheric nitrogen. Throughout the year, it sheds large quantities of nitrogen rich leaves that decompose rapidly and form rich humus. Often found growing in association with maize and beans (REMA, 2010).

2.7.1.6 *Moringa Oleifera*

Moringa oleifera is a small, graceful, deciduous tree with sparse foliage, often resembling a leguminous species at a distance, especially when in flower, but immediately recognized when in fruit. The tree grows to 8 m high and 60 cm. The leaves, a good source of protein, vitamins A, B and C and minerals such as calcium and iron, are used as a spinach equivalent. *M. oleifera* is suited to areas where strong winds and long, dry spells occur simultaneously, causing serious soil erosion.

The green leaves make useful mulch. *M. oleifera* provides wind protection, shade and support for climbing garden plants. The tree provides semi-shade, useful in intercropping systems where intense direct sunlight can damage crops (REMA, 2010).

2.7.1.7 *Alnus Acuminate*

Alnus acuminata grows to 30 m and 50 cm diameter at breast height at 30 years of age. The palatable, nitrogen-rich leaves make a useful source of emergency fodder. Reputed to be good for firewood, it is also useful for reforestation, soil reclamation on slopes and reclamation of unstable soils, as it grows well on slopes and the roots are lateral and extended rather than deep and confined. *A. acuminata* is a nitrogen-fixing species and the supply of organic matter and the control of soil moisture due to its shade (REMA, 2010).

2.7.2 Soil Conservation and Extension Policy in Rwanda

In Rwanda, there is policy change in the way in which soil conservation is applied in the field: the current approach of compulsion has given place to one of persuasion and cooperation. The current approach is based on passing laws or regulations governing land use, and enforcing these. Such 'agricultural rules', as they are called, commonly included forbidding cultivation on slopes of more than a certain steepness, forbidding cultivation within a specified distance from a water course, requiring the construction of bunds or other conservation works before permission was granted for land to be taken into cultivation (RNRA, 2012).

Enforcement is generally by warning or threat, backed by legal prosecutions in extreme cases. In Rwanda, this approach was mainly applied in the context of colonial government, and under conditions of relatively low pressure on land. Although now commonly derided, it achieved in its time a substantial measure of success in controlling erosion; an example is the complete coverage of large areas Rwanda with well designed and maintained systems of cut-off drains, bunds and waterways (REMA, 2010). The policy of applying conservation by prohibitive or compulsory means is now not effective.

There were always difficulties, particularly in that agricultural extension staff, whose job it was to help the farmer, did not wish to be associated with enforcement. In Rwanda, the policy was associated with colonial rule and thus became anathema to newly independent governments. Many of the rules are still on the statute books, but are no longer applied. The present policy is to apply soil-conservation measures through persuading farmers that it is in their interests to do so, and securing their cooperation. This is not simply a matter of prevalent attitude of mind: it is, in fact, a more effective approach. Unless a land-use practice has the support of the farming community, it will never be applied. Where a few individuals act contrary to the interests of the majority, some measure of enforcement will still be necessary, but this itself must come from within the local community (UNESCO, 2002).

Another trend in policy is away from soil conservation treated in isolation and towards its integration into farming systems as a whole. This is part of the growth of the farming-systems approach to development. Such systems of improved agriculture have been called 'conservation farming' or 'integrated land use' (REMA, 2010).

These trends are highly compatible, both with the nature of agroforestry and with its development through the approach of diagnosis and design. It is a fundamental aim of agroforestry design that systems should combine productivity with sustainability; thus, there is an immediate real and perceived benefit, whilst at the same time conservation is achieved. Many agroforestry practices are relatively simple to implement, and it has almost invariably been the case that they are put into practice by the farmers themselves, whether as indigenous practices or through adoption of innovations (RNRA, 2012).

The approach of diagnosis and design has the element of farmer acceptance and cooperation built into it. The farmers are consulted at the stage of diagnosis as to what is their perception of the problems of the system; these are very often likely to include low crop yields, although erosion mayor may not be perceived as one of the causes (REMA, 2010).

Local constraints, e.g. of labor, capital or supplies, are established and taken into account in designing improved systems. Any proposed changes are put to the farmers for their opinions when it may often be found that what the scientist considers to be 'improvements' are regarded locally in another light! The essential feature is that the former sequence in which technical design was followed by the problem of acceptance has been replaced in the diagnosis and design procedure by one in which acceptability is built into the system from the start. Since this approach is applied to the agroforestry system as a whole, it necessarily covers whatever elements of soil conservation it may include (RNRA, 2012).

The fact that agroforestry combines erosion control with soil fertility maintenance and production, makes it more acceptable to farmers than any other practices of erosion control. At the same time, its techniques are relatively inexpensive, and lie within the capacity of small farmers to implement. These aspects of agroforestry render it highly appropriate in the light of recent trends in conservation policy (REMA, 2010).

2.8 Knowledge Gap

Farmers in Rwanda depend on forest products such as timber, poles, fuel wood, fodder, litter, compost, medicine, and fruits plants and Agroforestry can respond to farmer's needs by protecting forest, making tree products such as firewood and fodder easily available to farmers, restoring fertility of land by decreasing soil erosion, adding nutrients through decomposition of leaf litter and nitrogen fixation, recycling leached-down nutrients and helping breakdown of nutrients in the subsoil by means of deep roots. Problems such as shortage of forest resources can be reduced by the mid hill farmers through retaining or keeping trees in various parts of their farmland along with crops for centuries despite having limited landholding (REMA, 2010).

Despite a strong interest from policymakers and investors and the on-going re-structuring of soil and forest management in Rwanda, a number of constraints hinder the agroforestry development. Rwanda's agricultural sector remains by a plethora of challenges thought all sub-sectors that include lack of inputs and service providers, land scarcity, lack of trainings and information and land degradation.

Although consisting of an oasis of opportunities yet to be explored, high population pressure and land tenure holding systems as well as the dependence on agriculture for household income is resulting in short fallow periods and subsequent reduction in yield levels of crops in the study area. Issues of awareness and lack of appropriate technologies keep coming up all the time. This is a serious concern considering that soil and forests are the essential components of the government's drive in rural development, food security and environmental protection.

There is no existing study on the use of innovative approaches to identify potential contribution of agroforestry practice to soil and water conservation in Rwanda. Even more alarming is the fact that no effort has been made to evaluate the effects that agroforestry might have on soil erosion control, fertility maintenance, farm production and biodiversity. This dissertation addresses these concerns by exploring the existing agroforestry practices; determining the impact of agroforestry on soil erosion control; evaluating the impact of agroforestry to maintenance of soil fertility and by determining the impact of agroforestry on farm productivity as well as the maintenance of biodiversity.

CHAPTER THREE

MATERIALS AND METHODS

3.1 The Study Area

The study will be conducted in Gasange, Kiramuruzi and Kabarore Sectors of Gatsibo District Eastern Province due to fact that the mounting pressure of exponential growth in human and livestock population in the area, which has been subjected to various pressure and misuse resulting in degradation of land, loss of biodiversity and declining cultivable land. These have increased the gap between demand and supply for rural needs fulfillment. Today, the existing allocation to agriculture and forestry are inadequate to meet the demand for food, timber, fuel, fodder, and other minor products. This is the right time to exercise option to convert low productive and less exploitable land into a productive resource by adopting agroforestry for diversification and sustainable biomass production. The high demand of grazing land and cattle feeds in the district caused soil erosion and agroforestry is perceived as a solution for both poverty reduction and soil erosion control. Within Eastern Province, Gatsibo is ranked fourth by poverty indicator after Rwamagana (30.4%), Nyagatare (37.8%) and Kayonza (42.6%) districts. Under half of the population (43%) of the district is poor (including extreme-poor) (RNRA, 2012).

Gatsibo District is delimited to the East by the National Park of the Akagera; to the North by the District of Nyagatare; to the West by the District of Gicumbi, to the South by the Districts of Rwamagana and Kayonza. Total area is of 1585 Km^2. The District of Gatsibo counts 14 Sectors including Gasange, Gatsibo, Gitoki, Kabarore, Kageyo, Kiramuruzi, Kiziguro, Muhura, Murambi, Ngarama, Nyagihanaga, Remera, Rugarama and Rwimbogo. It counts 69 cells and 603 villages (Imidugudu). The estimate terrain elevation above sea level is 1462 meters. The area is bounded between 1°35'30.66" of Latitude and 30°27'19.26" of Longitude.

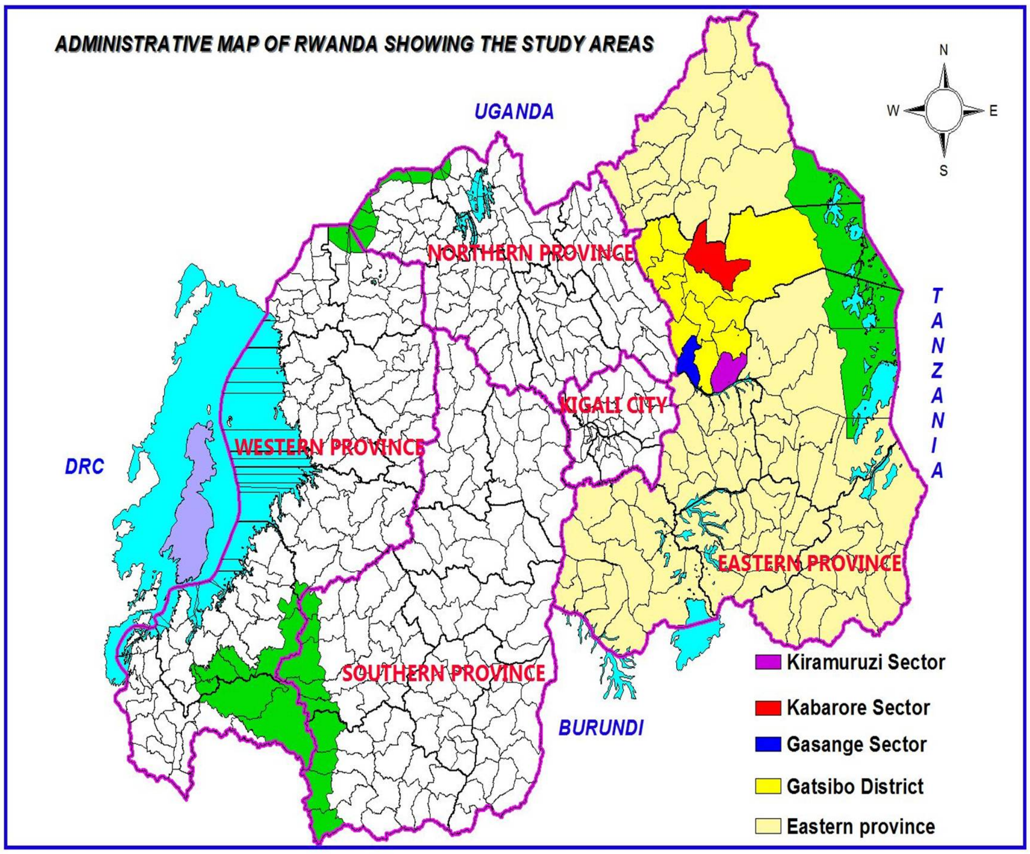

Figure 3.1: The Map of Rwanda Showing the Study Area

3.2 Study Area Biophysical Characteristics

3.2.1 Relief

The relief of the District of Gatsibo is characterized to the East by scarcely weak hills separated by valleys, dry during most of the year. To the West, Gatsibo has an injured relief. The region of Gatsibo is located in a granite depression of which the average altitude is of 1550 meter. The District of Gatsibo spreads itself on the plateau and the savannah of the East of the country. The topography of the zone is not largely mountainous and constitutes a potentiality for the introduction of the agricultural mechanization. This relief offers to Gatsibo a vocation agro pastoral and tourist (NISR 2012).

3.2.2 Population

The estimated total population of Gatsibo district in 2010–11 is 491,000, representing 19% of the total population of Eastern Province and 5% of the total population of Rwanda. Females comprise 52% of the population of the district and the majority of the population is young, with 55% of the population aged 19 or younger, and only 3% of the population 65 and above (NISR 2012).

3.2.3 Climate

The District of Gatsibo is characterized by two principal seasons: a long dry season of which the annual average temperature varies between 20,3°C and 21,7° C. The rain season is short and influences negatively hydraulic availability for the activities agro-sylvo-pastoral (NISR 2012).

3.2.4 Hydrography

Gatsibo District knows the weak rains and high temperatures. That limits the availability of water. In fact, apart from the river Umuvumba and Akagera as well as the lake Muhazi, there is not any other river exploitable by the inhabitants of Gatsibo. Gatsibo disposes also rivers namely Kanyonyomba, Rwangingo, Kabahanga, Kagina, Kagende, Rwagitima and Ntende. This hydrographic network combined with the aforementioned relief offers timeliness of irrigation (NISR 2012).

3.2.5 The Flora

The flora of the District of Gatsibo is characterized by a vegetation of kind steppe wooded. Its hills are covered with short grasses as well as small trees. Concerning afforestation, the District of Gatsibo has access to Eucalyptus and of Pinus. There are also different types of agro forest with predominant coffee in the North-West region of the District (NISR 2012).

3.2.6 The Wildlife

As for the wildlife, the District of Gatsibo has access to an inheritance of the former domain of hunt of Akagera national park with diversified birds notably the rapacious ones as the sparrow hawk, the owls, the partridges, the heroes, the ibis, the crows, the prick beef, etc. The hares, the wild boars, the monkeys and other rodents live the hills where exist again small natural shrubs. The hippopotamus are met in the river Umuvumba and in the lake Muhazi. The crocodiles exist also in certain valleys ladies as to Rwimbogo. The antelopes, the buffalo and ruminating other screws in the party occupied by the Akagera National Park (NISR 2012).

3.3 Research Methodology

3.3.1 Research Design

Descriptive or survey research design that attempts to describe and explain conditions of the present by using many subjects and questionnaires to fully describe the contribution of the agroforestry to soil conservation was applied. Gatsibo District was chosen to be the context of this study because of the mounting pressure of exponential growth in human and livestock population in the area, which has been subjected to various pressure and misuse resulting in degradation of land, loss of biodiversity and declining cultivable land. These have increased the gap between demand and supply for rural needs fulfillment. Today, the existing allocation to agriculture and forestry are inadequate to meet the demand for food, timber, fuel, fodder, and other minor products.

3.3.2 Target Population

The target population for this study was the small holder farmers of Gasange, Kiramururzi and Kabarore Sectors of Gatsibo District in Eastern Province, Rwanda and small holder farmers in these Sectors were considered in the study.

3.3.3 Sample Size and Sampling Techniques

For this study a purposive sampling followed by random sampling technique were employed in selecting the study sectors and respondents. Three sectors; Kiramuruzi, Gasange and Kabarore were purposively selected for this study basing on their populations (the lowest, the mid and highest populated households in the three selected sectors was 11248. In order to get a representative sample, the table and the formula of Bouchard (1990) was applied. To obtain the adjusted sample size for the households, the following formula was needed:

nc= n/1+n/N or simply n x N/N+n

nc= 68x11248 /11248 +68= 68

Where: N: Population size

n: Sample size for a finite population which is equal to 68 from Bouchard table

nc: Adjusted sample size for a finite population

The sampling unit for this study was the household (HH) which consisted of one or more people living in the same dwelling and sharing at meals or living accommodation, consisting of a single family or some other grouping of people. The sampling frame was a list of all households in the three study sectors.

Using the table from the sample population size, the sample size is determined as follows: Given that our population size (N) lies between 10000 and 50000 HHs, it corresponds to the sample of 67.59.6 ~68 HHs with marginal errors of 10% with a precision of 90%. A simple random sampling technique was then applied to select respondents from each of the study Sectors.

Member of the population had an equal chance of being selected as subject. Each individual as assigned a unique code. Each code was placed in a sink and mixed thoroughly. The survey coded tags were then picked from sink. All the individuals bearing the numbers picked were the subjects for the study. Seven key informants were purposively selected and these included experts and local leaders which made 75 HHs as the total sample size.

3.3.4 Data Sources

The data required for this study were collected from both primary and secondary sources. The primary data were obtained from randomly selected sample households using a survey questionnaire. To have an overall view of the study area land-use and land management, a reconnaissance survey was conducted prior to the questionnaire survey.

3.3.5 Data Collection Methods

Both primary and secondary data were collected in this study. A combination of methods was employed in collection of primary data including questionnaire survey and in depth interviews with key informants.

3.3.6 Primary Data

Primary data was collected from questionnaire administration and interviews with selected respondents. Participant observation was also applied.

3.3.7 Secondary Data

Secondary data related to socio-economic features of the District, were collected from District and national reports, maps, internet as well as published and unpublished documents of other organizations. Information was also obtained from published and unpublished books, journals, newsletters, periodicals, articles and the internet.

3.4 Data Analysis

The data were coded, categorized and entered in computer and analyzed using computer software packages MS Excel and SPSS 16.0 (Statistical Package for Social Science) where frequency distribution was mostly used. The results are presented through text, Tables and Figures accompanied by subsequent interpretations.

CHAPTER FOUR

FINDINGS AND DISCUSSION

4.1 Introduction

In this Chapter, the research findings are presented, analyzed and interpreted. These are mainly based on the set of objectives and are in conformity with the research questions. Bar charts were used to present the findings and all results are presented in term of frequency (Percentages). Tables with detailed information have been appended.

4.2 Demographic Characteristics

4.2.1 Age of Respondents

Results in Figure 4.1 show the age groups of respondents. Four age ranges had been identified among the heads of households: between 18-25, 26-35, 35-50 years and from 51 years and above.

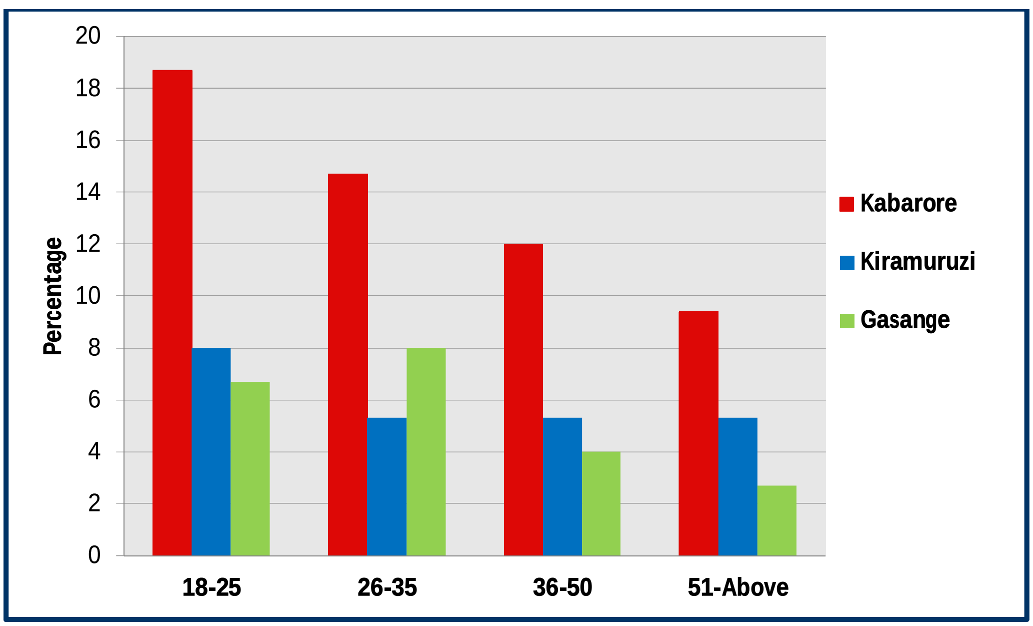

Figure 4.1: Age Distribution among Households' Heads

In all communities, a majority of respondents were within the economically active age group of 18-25 (18.7%, 8% and 6.7% in Kabarore, Kiramuruzi and Gasange Sectors respectively), followed by the 26-35 age range. The rest were between 36 and 50 and above 50 years of age. These finding suggest that the population is generally young. The similar findings have been obtained by NISR (2012) in a population survey in which the majority of the population was found to be young and economically active. During the planning of agroforestry practice, it is important to consider the influential age groups, but care still needs to be taken so that other groups are not marginalized.

Mapes, (1862) proved that young farmers are assumed to have a good knowledge of soil conservation measures due to access to information. The proportion of elderly farmers is 14%, an age group in which labor shortage can be a barrier to practice new technology like agroforestry.

4.2.2 Gender Status of Respondents

Gender characteristics are directly related to the supply and demand conditions for basic human needs, such as food, shelter, health and educational facilities which in turn directly or indirectly influence the adoption of soil conservation technologies for a farming system. Results in Figure 4.2 show the gender distribution of respondents.

In all study Sectors; overall, 60% of respondents were males as against 40% females. This may be because household heads were those that answered the questionnaire and traditionally, men are usually the household heads.

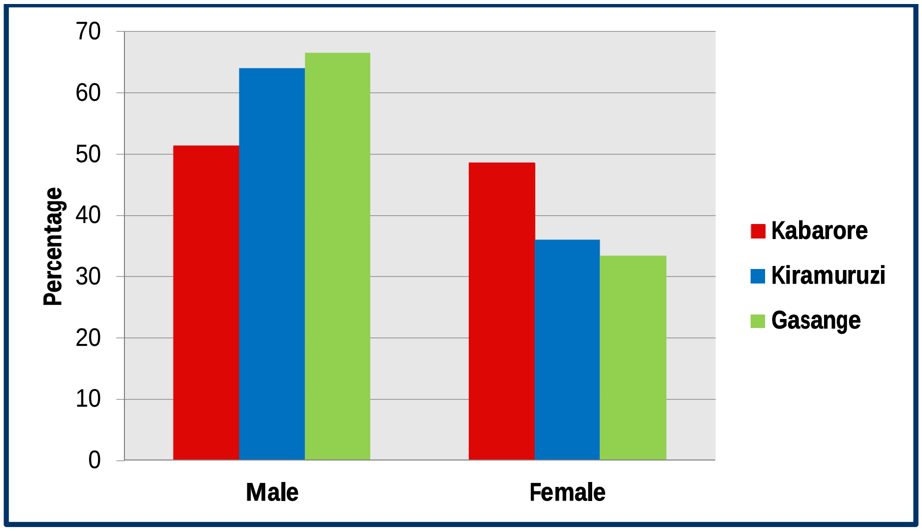

Figure 4.2: Gender Status of Respondents

4.2.3 Education Level of Respondents

Results in Figure 4.3 show the education level in the study area. Three educational levels amongst the household heads surveyed were identified, including: illiterate (meaning no formal education), basic level and high level education.

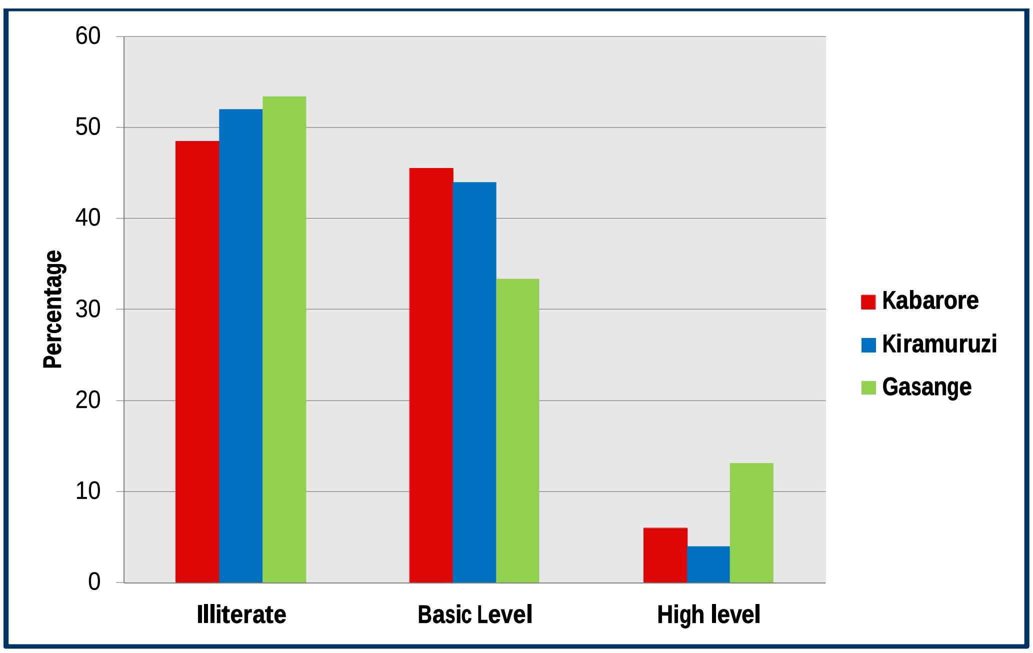

Figure 4.3: Education Status of Respondents

The majority of respondents (Averagely 54.3%) didn't receive any formal education (illiterate), while 41% had basic education and only 5% had higher education. Kumar and Nair (2013) find that the high level of illiteracy among the study population has important implications for the practice of agroforestry because education is known to have a positive correlation with many variables.

4.3 Socio-economic Characteristics

4.3.1 Household Heads' Income Sources

Past researches have shown a link between income sources and soil conservation practices. Specifically, agroforestry is practiced more by individuals with a higher income level (FAO, 2010). The different income sources among respondents are presented in Figure 4.4.

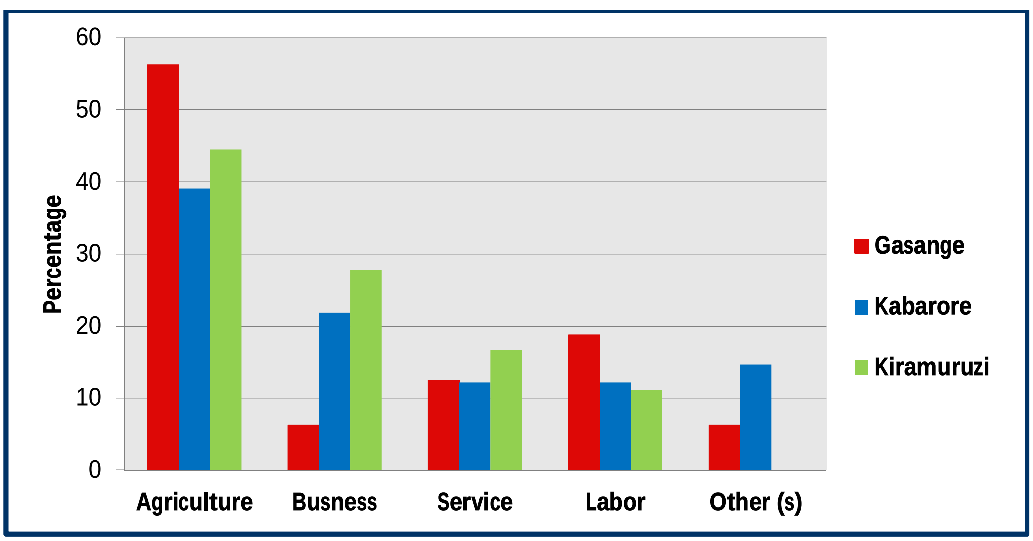

Figure 4.4: Sources of Income for Respondents

The results in Figure 4.4 suggest that the majority of respondent (44%) are in agriculture sector. These findings stress the need of modernizing, improving and empowering the agriculture sector that provide almost the total of households' needs.

The implementation of soil conservation practices in general and agroforestry in particular can contribute to achieve this. Past study (Current,*et al.*, 1995) indicated that income sources play a significant role in agroforestry systems adoption. Therefore, financial assistance is required to promote agroforestry practice.

4.3.2 Farmland Size and Distribution

Land in the study area is scarce mainly due to population pressure. The majority of farmers' land size ranges from 1 to 3 ha (Figure 4.5).

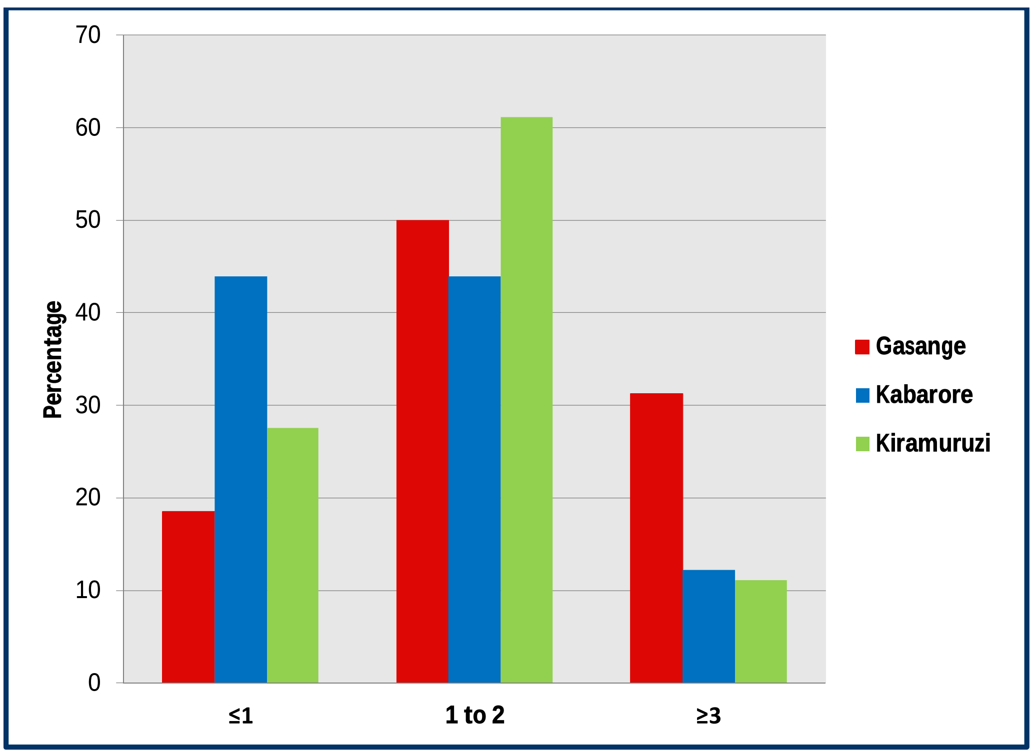

Figure 4. 5: Farm Size Distribution

The findings in Figure 4.5 indicate that in the three study Sectors, the majority of farmers own between one and two hectares. Only 31.25%, 12.2% and 11.1% of respondents from Gasange, Kabarore and Kiramuruzi Sectors respectively own 3 or more hectares. About 43.9% of respondents from Kabarore Sector own less than 1 hectare and the noted land scarcity in this Sector may be explained by the high population pressure as Kabarore is the most populated one among the three study Sectors.

The findings indicate that land in the study area is scarce probably due to population pressure. Limiting cultivable land loses an opportunity to increase soil fertility and reduce soil loss from erosion. Rose (1988) indicated that larger farm size was associated with stronger intentions to adopt soil conservation. Farm size was related to the importance farmers placed on conservation. By crops association, agroforestry brings solutions to land scarcity.

4.4 The Present Status of Agroforestry Practice in the Study Area

4.4.1 Farmers' Involvement in Agroforestry Practice

Results in Figure 4.6, shows that the respondents practice Agroforestry in order to prevent land degradation, especially soil erosion. In Gatsibo District, most of farmers use a number of traditional and improved soil conservation technologies. These technologies include application of manure, traditional and newly introduced cut-off drains, plantation of both traditional and newly introduced trees, bench terraces, leaving crop residues in the field and fallowing on the farm.

Before valuing the benefits of Agroforestry on soil conservation, this study judged important to know if all respondents were practicing agroforestry. Each of respondents (100%) practices at least one system of agroforestry on his farm. The findings in Figure 4.6 suggest that 67% of respondents in the three study Sectors combine more than 2 or more systems on their farms. However there are few respondents (33 %) who do not practice more than one practice on their farm.

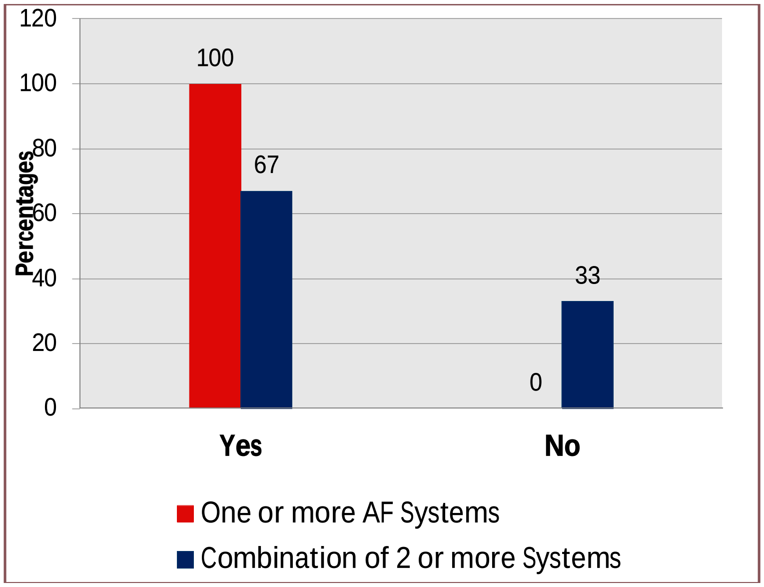

Figure 4.6: Involvement of Respondents in Agroforestry Practices

4.4.2 Major Agroforestry Systems and Practices

The main agroforestry practices found in the study area are described in the Figure 4.7. All the farmers are involved in agroforestry practices. Farmers raise and protect fodder, fruit and fuel wood in and around their plots and households whereas timber species are raised in the degraded land. From the time immemorial, farmers have been practicing different agroforestry practices.

They are well known for their shading effects. Farmers well know about maintaining height of the improved variety of fodder trees. They have planted the fruit trees in their farmlands for income and subsistence. The existing agroforestry practices in the study area contain different types of perennial and annual crops. Different tree species such as fruit, fodder, fuel wood and timber yielding trees come under perennial crops in which fodder species are most commonly raised whereas rice, maize, millet, pulses and vegetables come under the agricultural crops.

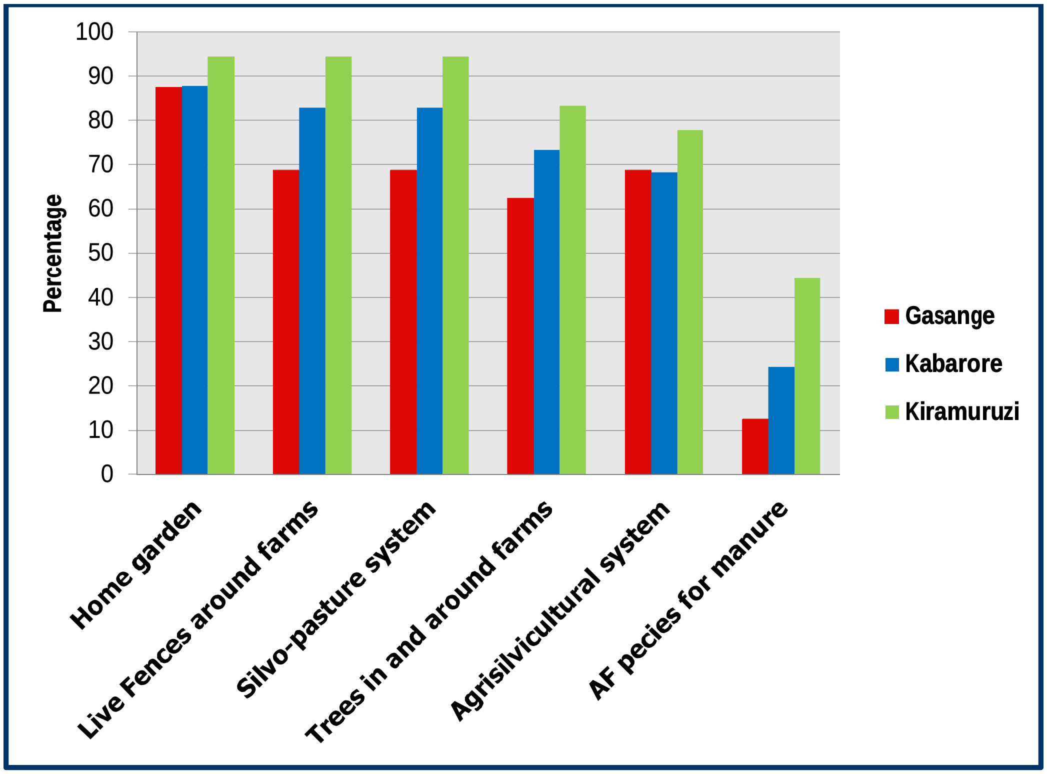

Figure 4.7: Major Agroforestry Systems and Practices in Study Area

4.4.3 Trees Species Diversity in the Study Area

The findings in Figure 4.7 show that home garden, Live fences around farms and Silvo-pasture are the common and most frequent agroforestry systems in the study area (94.4 % of respondents from Kiramuruzi Sector with the same trend for other two study Sectors). Home garden consists of land management practice in which fruit and fodder trees, annual crops or vegetables crops are cultivated in the same unit of land. Farm lands are surrounded by lines of trees or shrubs planted on the farm boundaries, borders of home compounds, home gardens, and pastures.

According to respondents of study site, the practice primarily evolved due to the need of protecting crops and vegetables from animals and humans. Silvopastural system includes combination of woody perennials with pasturage in the same land management unit. Likewise, trees in and around the agricultural fields is the common practice found in the study area. Fodder trees are planted in the terrace rises, and abandoned land inside the plots land and timber trees were raised in the border of the land, near the streamlets, landslide areas and near to the forest and grass species in sloppy riser and bund of terrace edge and annual crops; maize, millet on terrace in the plots land.

Agrisilviculture is another common and frequent agroforestry practice practiced by 77.8% of the respondents from Kiramuruzi and the same trend was noted in the two other Sectors. Agrisilviculture is a land management in which trees are simultaneously managed with crops i.e. concurrent production of perennial woody trees and annual crops. Plantation of multipurpose tree species on terrace edge, sloppy riser and crop production on the terraces are more common practices. A number of farmland plant species including fodder, firewood, medicine, fruits, timber and live fences are found in study sites. Figure 4.8 presents the status of species diversity in the three study sectors.

Figure 4.8 shows that fodder trees were found to be the most common and frequents reported by 94.4%, 85.4% and 81.25% of respondents from Kiramuruzi, Kabarore and Gasange Sectors Respectively, followed by fruit trees (94.4%, 82.9% and 81.25%) and timber trees (50%, 51.2% and 67.8%).

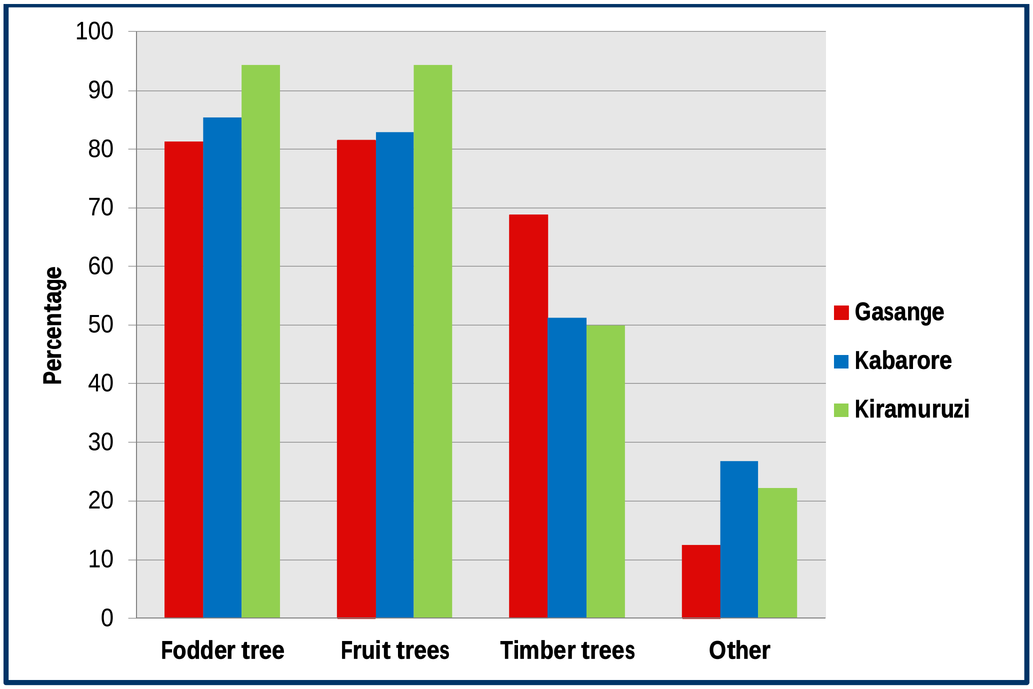

Figure 4.8: Trees Diversity in the Study Area

The found tree species include *Calliandra calothyrsus Eupatrium spp,Saccharum spp,Imperata cylindrical,Cedrela serrata, Grevillea robusta Leucaena diversifolia, Mimosa scabrella, Moringa oleifera and Alnus acuminate.*These findings are not substantially different from those of ICRAF (1987b) in a study conducted in Rwanda in which the above mentioned species were found to be the most preferred by Rwandan farmers.

4.5 Reasons for Adopting Agroforestry

Results in Figure 4.9 indicate that majority of respondents adopted modern agroforestry mainly because of the many benefits that agroforestry provided including agroforestry products (93.75%, 97.6% and 94.4% of respondents from Gasange, Kabarore and Kiramuruzi Sectors respectively), followed by erosion control, sustainable agriculture and increased income.

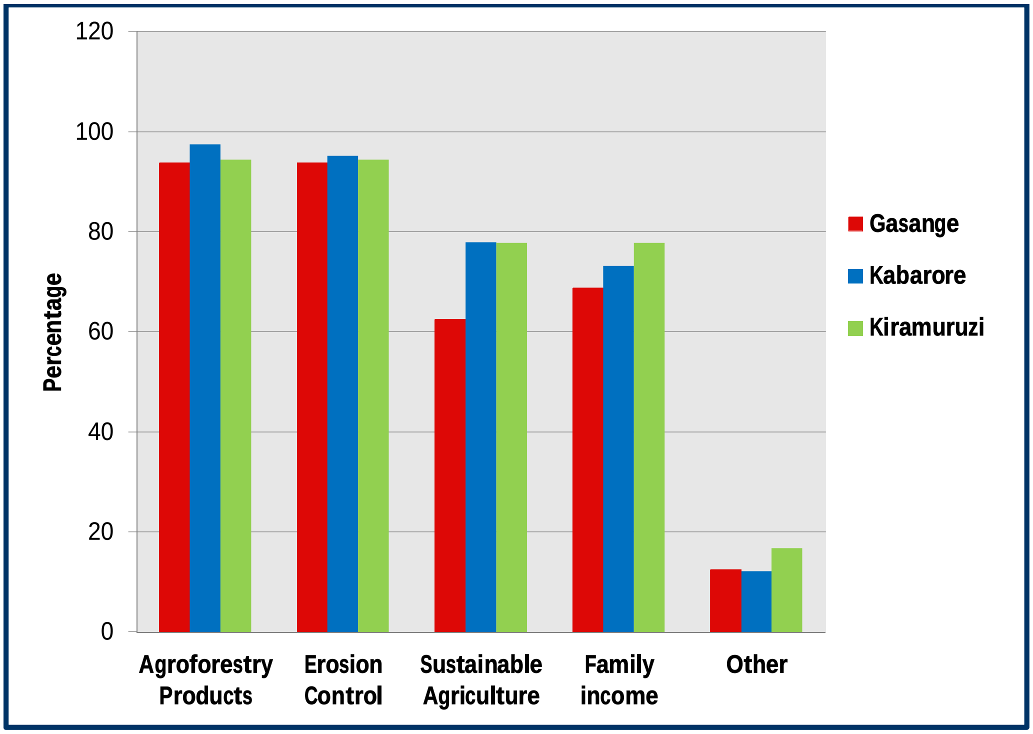

Figure 4.9: Motivation for Adopting Agroforestry

Other section of Figure 4.9 included reasons such as diversity in farm produce, encouragement from Government, encouragement from officials, food security and poverty alleviation, and curiosity among others as reasons for adopting agroforestry. These findings suggest that economic gain is a crucial factor in agroforestry systems adoption and efforts need to be put in increasing yields. In a study conducted by Mires (1997), economic gain was cited as the most important reason why landowners may adopt an agroforestry system.

4.6 Perceived Contribution of Agroforestry to Soil Conservation

A hundred percent of respondents believe that agroforestry contributed to soil conservation. This study collected data on how has agroforestry contributed to soil conservation and the results are presented in the Figure 4.10.

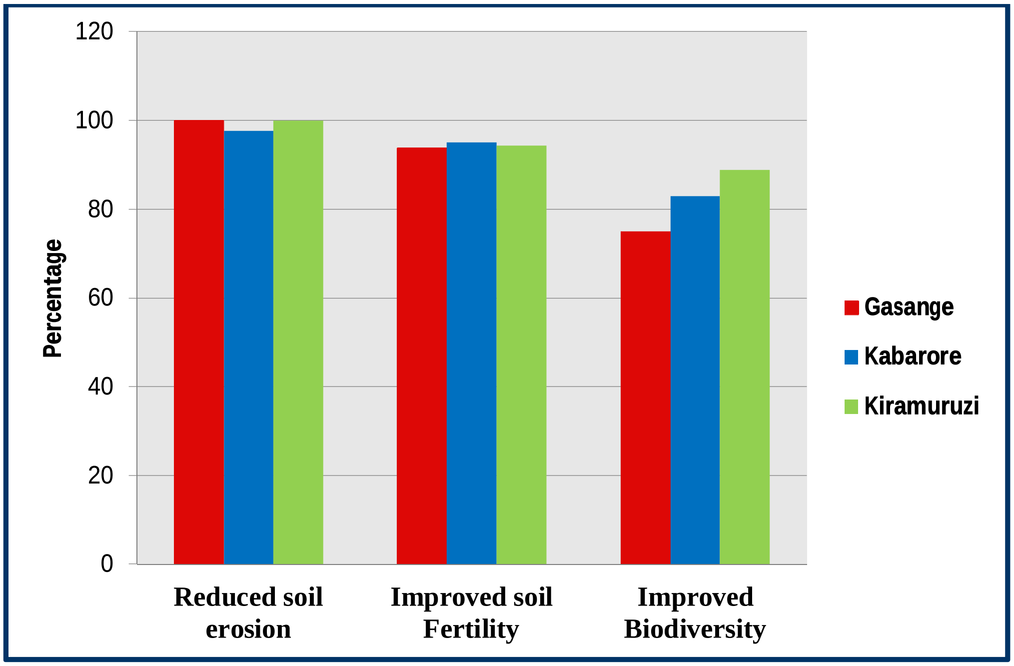

Figure 4.10: Perceived Contribution of Agro Forestry to Soil Conservation

The findings in Figure 4.10 indicate that "reduced soil erosion" is perceived as the most important contribution to soil conservation, mentioned by 100% of respondents In Gasange and Kiramuruzi Sectors. Others are improved soil fertility and productivity (93.75%, 95.1% and 94.4 %) and improved biodiversity (75%, 82.9%, 88.9%) of respondents from Gasange, Kabarore and Kiramuruzi Sectors respectively) (82.6%).

These findings are not different from those of Young (1987) who concluded that appropriate agro forestry systems control erosion, maintain soil organic matter and physical properties, and promote efficient nutrient cycling. There is a considerable potential for soil conservation through agro forestry, both in control of erosion and by other means of maintaining soil fertility. This potential applies to many agro forestry practices and over a wide range of climatic zones and soil types, (Young, 1987).That means agro forestry has the potential to make a major contribution to soil conservation and sustainable land use.

4.6.1 Agroforestry and Soil Erosion Control

Agroforestry has a potential for erosion control through the soil cover provided by tree canopy and litter, in addition to the role of trees in relation to the runoff-barrier function. The integration of conservation with improved farming in general, coupled with that of securing cooperation of the farmers at an early stage, accords well with the approach of agroforestry diagnosis and design (Raintree, 1987). Respondents were asked if they do believe that agroforestry contributed to soil erosion control. The results are presented in Figure 4.11.

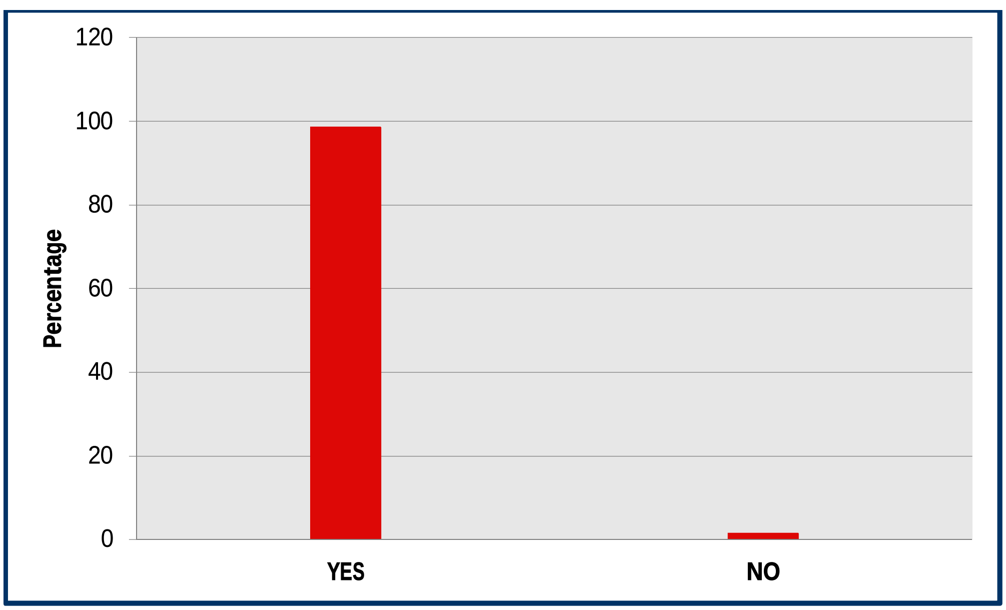

Figure 4.11: Contribution of Agroforestry to Soil Erosion Control

Findings in Figure 4.11 suggest that about 98.6% of respondents believe that agroforestry contributes to soil erosion. In a similar study, Lundgren, (1980) gave a notable practical example of cover control of erosion reported from a moist sub-humid highland area in Tanzania. On an agricultural plot on a 20-25° slope, erosion was kept to well below 1 t/ha/yr by cover-based management, including mulching with weeds and crop residues.

In a research on Soil and Water Conservation Research conducted in India by Singh *et al*. (1981), terracing has been found to be an effective means of control, but requires high labour inputs. An alternative land-use system has been devised, in which slopes are divided into three parts namely upper slope: retained under natural forest, middle slope: pasture with fruit trees on individual semi-circular terraces ("hort-pastoral system') and lower slope: terraced arable use. A set of 13 experimental watersheds has been monitored at Shillong, including agroforestry land use.

The implication is that agroforestry plays a great role in soil conservation and should be extended to all households and need to be supported by government. To fulfill the basic demands of forest resources programs for the planting and management, better access to seedling, extension program and training activities should be conducted for the poor farmers.

4.6.1.1 The Way that Agroforestry Contributes to Erosion Control

The study collected information on the way that agroforestry contributes to erosion control and the Figure 4.12 presents the findings.

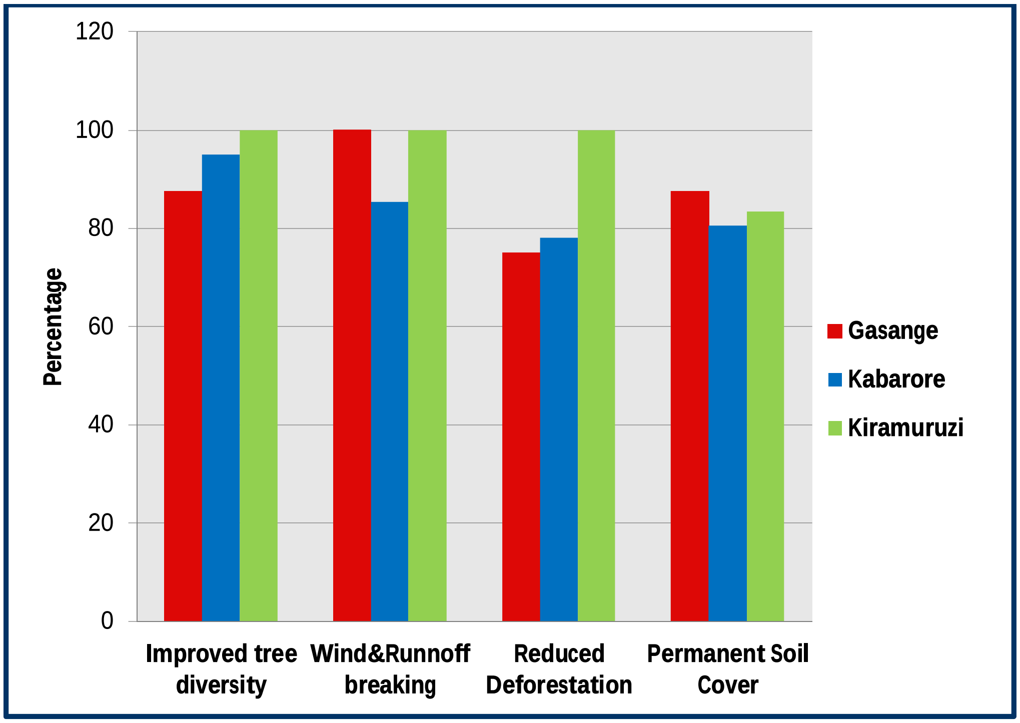

Figure 4.12: The Way that Agroforestry Contributes to Erosion Control

From Figure 4.12, the improvement of tree cover was the most frequent mentioned by 100% of respondents from Kiramuruzi Sector as the way that agroforestry contributes to soil erosion control. Other two study Sectors followed the same trend. Wind and runoff breaking, reduced deforestation, permanent soil cover and availability of pasture are other mechanisms by which the agro forestry contributes to erosion control. For the impact of trees on erosion-control structures, large improvements to soil fertility arise from the reduction in losses of organic matter and nutrients attributed to erosion control; the trees have a supplementary effect through addition of litter.

In a research by Young (1989), it was indicated that a higher plant density and a better rate of growth give more cover and increased protection (Hudson, 1983).

Erosion under cereals can be greatly reduced by intercropping with leguminous cover plants such as *Stylosanthes* or *Desmodium* (El-Swaify,*et al.*, 1984).

This stresses the greatest potential of agroforestry and its capacity to supply and maintain a ground cover. The direct effects of the tree canopy in providing cover are less than those of ground litter and a soil litter cover, maintained throughout the period of erosive rains, frequently reduces erosion to within acceptable levels, even without additional measures of the runoff-barrier type. Thus the direct prevention of soil erosion is most effectively achieved by a cover of surface litter, consisting of crop residues, tree pruning or both. The role of the tree canopy is to provide a supply of leafy material, through direct litter fall or pruning, sufficient to maintain this surface cover (Siderius, 1986).

4.6.2 Contribution of Agroforestry to Maintenance of Soil Fertility and Soil Productivity

Given the fact that population pressure on land has led to more or less continuous arable cropping over wide areas, erosion is likely to be one cause of the low yields commonly occurring on such land. Secondly, the main causes of yield reduction by erosion, in the short and medium terms, are lowering of fertility through loss of organic matter and associated nutrients, together with the effects of organic-matter loss on soil physical properties. In dry regions, loss of soil moisture by runoff is a further important factor. Hence the problem of erosion control, in the sense of controlling the mass of soil removed, is closely linked to the problem of maintenance of fertility (Siderius, 1986).

Respondents were asked if they do believe that agroforestry contributed to maintenance of soil fertility and soil productivity. The results are presented in the Figure 4.13.

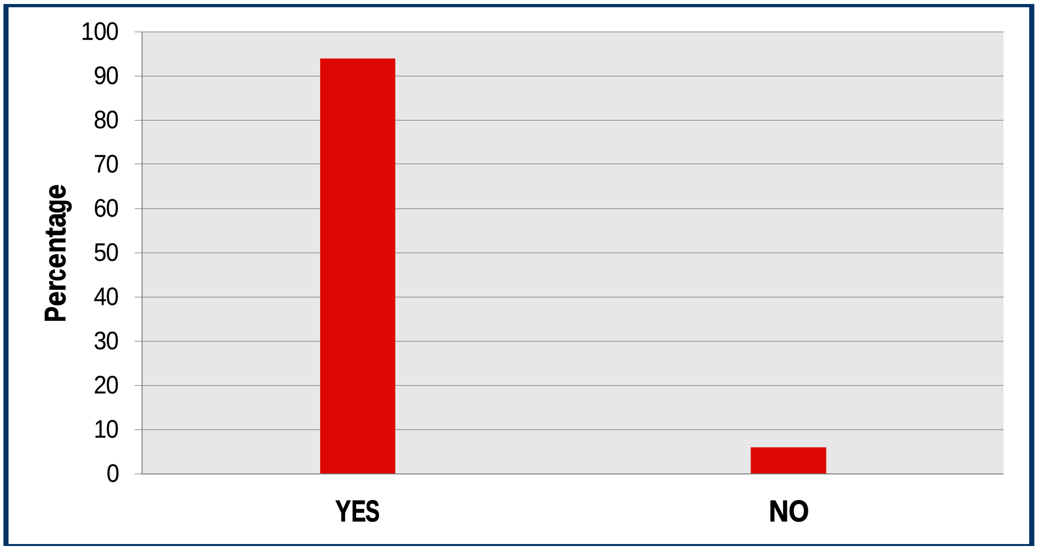

Figure 4.13: The Perceived Contribution of Agroforestry to Maintenance of Soil Fertility and Productivity

As presented in Figure 4.13, about 94% of respondents from all study Sectors believe that agroforestry contributes to soil fertility improvement and productivity. According to Peake (1986) in a similar study, the significance of this question for agroforestry lies not in any specific technical potentialities of agroforestry, but in establishing the basic importance of soil conservation from a social and economic point of view. The implication is that aid and investment have to be justified on the grounds of maintaining food production and providing an economic return on investment.

4.6.2.1 Agroforestry and Soil Fertility

There is a clear scientific evidence for beneficial effects upon soils of some systems of trees on cropland and plantation crop combinations. Although lacking evidence of this kind, there is no doubt that home gardens maintain soil fertility. The labor input of farmers attests the effectiveness of biomass transfer as a method of fertilization (Young, 1989). This study collected information on the way that agroforestry contributes to soil fertility improvement and the Figure 4.14 presents the findings.

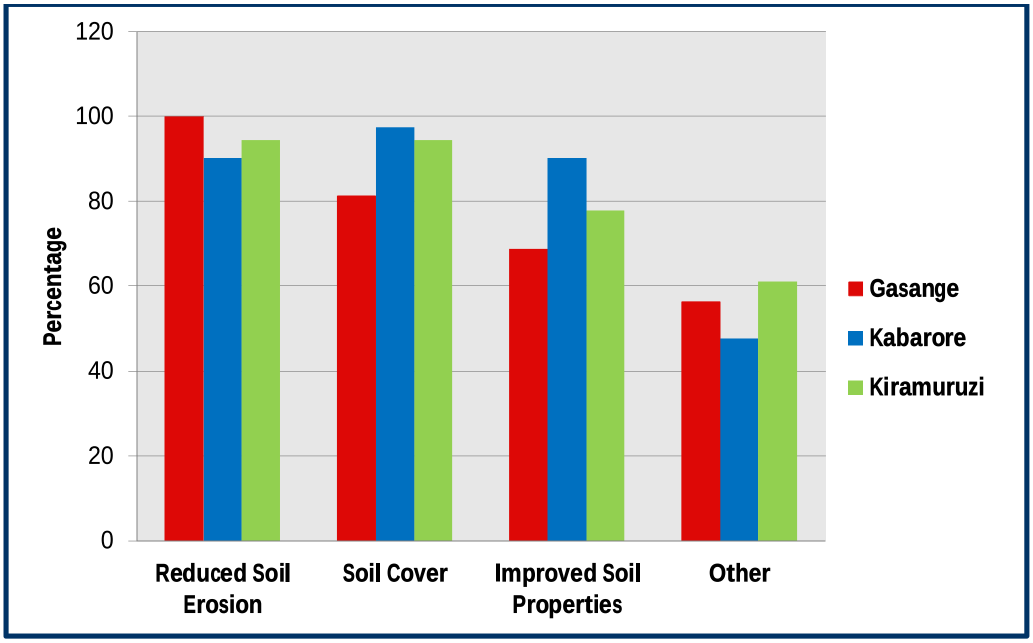

Figure 4.14: The Perceived contribution of Agroforestry to Soil Fertility Improvement

The findings in Figure 4.14 indicate that the soil erosion reduction is the most frequent contribution as mentioned by 100% of respondents from Gasange Sector with similar trend for Kabarore and Kiramuruzi Sectors as the way that agroforestry contributes to soil fertility improvement. Others include soil cover improvement (97.5% in Kabarore) and improved soil properties (90.2% in Kabarore Sector).

According to Young, (1989) in a comparable research, whilst intended primarily to control wind erosion, there is an apparent potential to make use of the soil fertility effects of trees in agroforestry practice. The spreading of leaf litter on crops being achieved by the wind is very contributing.

This implies that modern practice should be to design windbreaks of several tree and shrub species with differing shapes, which gives opportunity deliberately to include some of the known soil-improving species that occur in semi-arid areas, such as *Acacia albida*, other acacia species, *Prosopiscineraria* and *Azadirachta indica*. It appears possible, through imaginative design of windbreaks, to achieve erosion control, microclimatic amelioration and improved soil fertility, a combination of high potential value to the semi-arid zone.

4.6.2.2 Agroforestry and Soil Productivity

Agroforestry is a highly practicable management option at the farm level. It requires neither substantial capital nor machinery, and the necessary skills for tending trees can be learnt by farmers with limited formal education. The main inputs required in agroforestry, additional to those in agriculture, are supplies of tree germplasm and seedlings. Whilst there may be temporary local shortages, there are no intrinsic supply constraints. Local tree nurseries are simple and relatively cheap to construct.

There is nothing in agroforestry development projects comparable to the level of expense involved in, say, construction of dams or roads. The supply constraint of fertilizers is likely to be reduced or unchanged. In present-day agroforestry development, the major costs are research and training. Whilst these will continue to be necessary, their magnitude at present is a temporary phenomenon, stemming from the rapid growth in awareness of the potential of agroforestry for development. With respect to inputs and capital, therefore, agroforestry is a relatively undemanding form of development, with no serious supply constraints (FAO, 1984). Information about the productivity impact of agroforestry was gathered and the Figure 4.15 presents the findings.

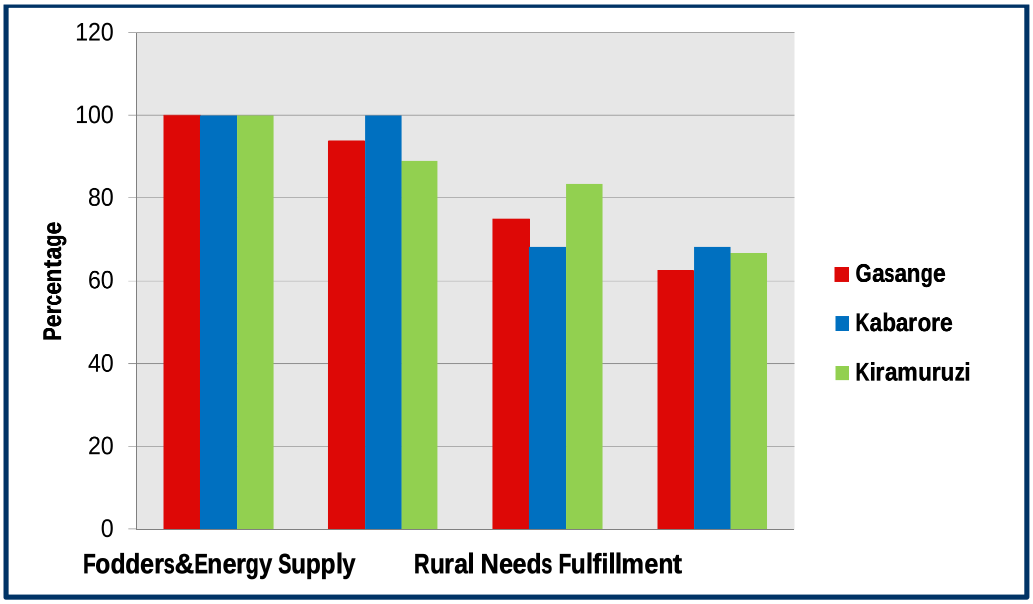

Figure 4.15: The Perceived Agroforestry's Benefits from Improved Soil Productivity

The findings in Figure 4.15 suggest that 100% of respondents in all study Sectors benefited from agroforestry in terms of fodders and energy supply. Others benefits included income generation (mentioned by 100% of respondents from Kabarore Sector), rural needs fulfillment (83.4% in Kiramuruzi Sector) and the increase of yields (63.8% in Kabarore Sector).

Agroforestry provides all types of forest products for meeting needs of households. Rural farmers depend on the farm trees for fodder, timber, litter, animal bed, fruit and medicine. Contribution of farm trees as timber is very small as compared to nearby forest, but small pole and agricultural tools are supplied from the farm trees. Most of the farmers used firewood for cooking food. Farm trees supplied almost the total annual firewood consumption; remaining firewood is collected from nearby community forests. Only collection of dry wood is allowed in the community forests. So there is no alternative to dependency on farm trees for firewood supply in the near future.

Fodder trees not only provide fodder to the livestock but also provide a substantial amount of fuel wood to meet the household needs of rural energy. Fodders by-products are also used for cooking livestock concentrate feed in separate stove. Most of the fodder trees are lopped during the dry period when green grasses are not available. During rainy season, fodder is also supplied to the goats. Farm trees fulfill about more than half of total fodder supply. Almost all fruits are supplied from the agroforestry. It shows that agroforestry have major contribution for the fruit, fodder and firewood supply of hill farming system whereas the timber supply from the agroforestry cannot be seen satisfactory due to the longer rotation period and more shading effect of timber species in faming system.

4.6.3 Agroforestry and Maintenance of Biodiversity

According to Bichier, (2000) in a research on “Agroforestry and Maintenance of Biodiversity”, agroforestry provide important habitats for biodiversity, ecologically sustainable buffer zones for protected areas, a high quality matrix that promotes movement between forest fragments, and ecosystem services such as pest control, pollination, and erosion control. This research sought to assess the impact of agroforestry on maintenance of biodiversity and the Figure 4.16 presents the findings.

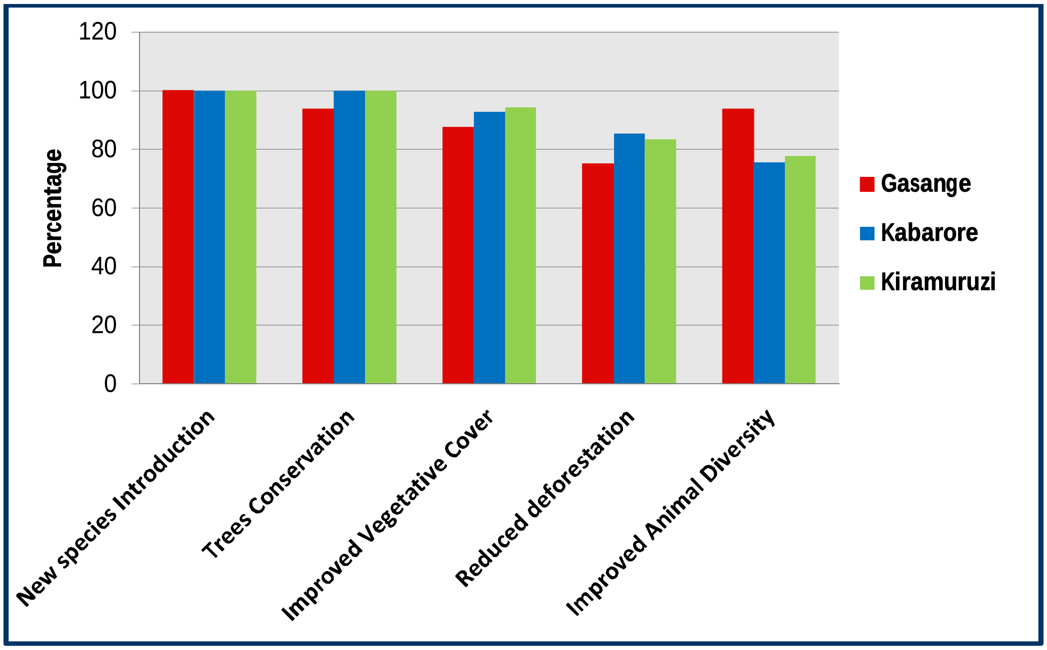

Figure 4.16: The Perceived Agroforestry's Benefits from Biodiversity Maintenance

The findings in Figure 4.16suggest that the introduction of new species as the contribution of agroforestry in maintenance of biodiversity was the most frequent mentioned by 100% of respondents in all study Sectors, followed by conservation trees species (mentioned by 100% of respondents from Kabarore and Kiramuruzi Sectors). Others contributions are the improved vegetative cover, reduced deforestation and the improved animal diversity.

Traditional agroforestry practices benefit biodiversity through in-situ conservation of tree species on farms, reduction of pressure on remaining forests, and the provision of suitable habitat for plant and animal species on farmland. Bichier, (2000) in a similar research concluded that agroforestry provide important habitats for biodiversity, ecologically sustainable buffer zones for protected areas, a high quality matrix that promotes movement between forest fragments, and ecosystem services such as pest control, pollination, and erosion control. Traditional, often complex agroforestry systems are more supportive of biodiversity than mono-crop systems, although even they are no substitutes for natural habitat on whose proximity they may often depend for high levels of wild biodiversity. Likewise, live hedges of *Leucaena* and *Calliandra* have resulted in substantial reduction in soil loss in Rwanda (Roose, 1988).

Studies conducted in East Africa and the Western Africa (Benge, 1987) showed that agroforestry systems usually contain more than half of the tree species that are found in nearby primary forests. It must also be recognized that agroforestry has potential to threaten biodiversity. The introduction and colonization of invasive alien tree species has the potential to replace less aggressive indigenous plant species. Agroforestry plays a vital role in achieving sustainability in the hills farming system. It plays a better role in increasing agricultural productivity by nutrient recycling, reducing soil erosion, and improving soil fertility and enhancing farm income compared with conventional crop production. Furthermore, it also has promising potentials for reducing deforestation while increasing food, fodder, and fuel wood production.

The implication is that maintaining diversity in approaches to management of agroforestry systems, along with a pragmatic, unidiomatic view on natural resource management, will provide the widest range of options for adapting to changing economic, social, and climatic conditions.

4.7 Farmers' Awareness and Perception on Soil Conservation Practices

Soil conservation practices found in the study area include: terracing, intercropping, crops rotation and agroforestry. Respondents were asked if they knew anything about soil conservation in general and agroforestry in particular. The Figure 4.17 presents the findings.

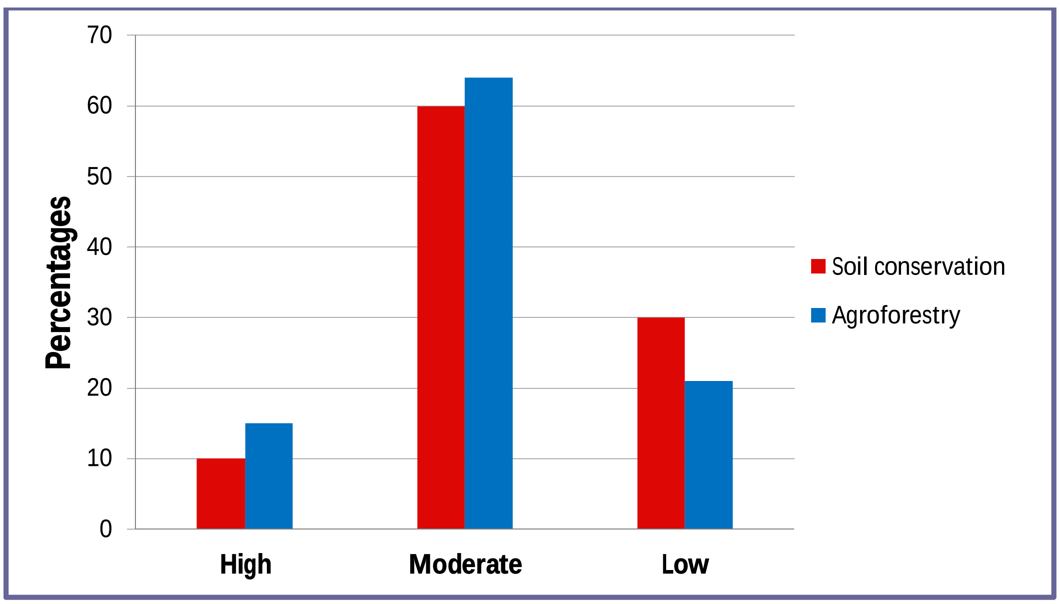

Figure 4.17: Farmers' Awareness in Soil Conservation Practices

Results in Figure 4.17 showed that majority of respondents in all study Sectors were not aware enough about soil conservation practices in general and agroforestry in particular. However, people are likely to be more aware about agroforestry than soil conservation in general. This may be because all respondents practice at least one system of agroforestry without knowing that it is one of the soil conservation measures.

Awareness of soil erosion problems has been shown to be positively correlated to the adoption of soil conservation practices. Sanchez (1987) found that farmers who were more aware of an erosion problem were more likely to adopt conservation measures. The perception of soil erosion problems is a significant factor for both the number of practices used and the conservation effort expended and the perception of the problem enhances and reinforces conservation effort. In other research, it appeared that farmers who perceived soil erosion as a relatively serious problem had greater intentions to adopt soil conservation.

Similarly, Sanchez (1987) observed that past efforts at promoting soil conservation focused on the provision of information to farmers in an attempt to change their attitudes. They noted, however, that attitudes and behavior are not perfectly correlated and suggest that there ought to be a focus on behavioral change in conservation programs.

There is a wide range of methods that should be used to raise awareness. A combination of all, or as many methods as possible, will assist in reaching the desired impact which is to inform all people of the importance of soil conservation in general and the agroforestry in particular. It is however, important to choose the communication channels and materials that are appropriate for each target audience and for the specific situation of the municipality. Examples include slogans, billboards, exhibitions, flyers, booklets, personal visits, campaigns, and to educate on site.

4.8 The Need for Research

At present, there is an explosion of activity in agroforestry research, the result of the rapid growth in awareness of its potential. Because of the urgency of the problems, brought about fundamentally by population growth and pressure upon natural resources, agroforestry is trying to achieve much in a short time. This calls for the structured planning of research. Respondents were asked if they fink researches in soil conservation are needed, if there have been any research in the study area before and if the findings were published and made available. The figure 4.18 presents the results.

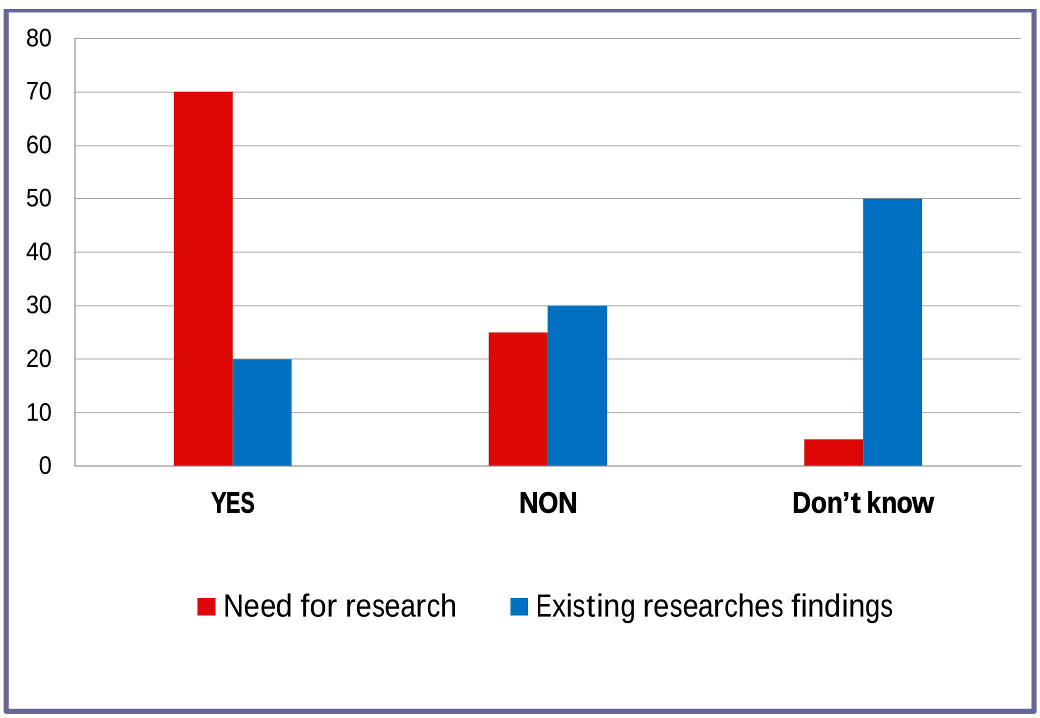

Figure 4.18: Researches on Agroforestry's Contribution to Soil Conservation

The study results indicate that 70% of respondents from all three study Sectors believe that researches are needed. Only 20% of respondents responded by “yes” to the question asking if there were any existing research findings on the role of agroforestry in soil conservation (Figure 4.18).

According to Young (1987), agroforestry systems are highly complex; involving the interactions of at least two plant components with each other and with climate and soil. Rural extension agents and farmers need advice on what tree species are appropriate to plant, in what number and arrangement, and with what management practices. Locally conducted trials of prototype systems, on-farm as well as on station, are the level of research which directly precedes such advice.

Previous researches may have been conducted but residents are not aware of their existence. This is a serious challenge because, if the District environmental officers and Sector officers, communities, NGOs, associations, private companies and advisers do not understand various benefits of agroforestry and its contribution to soil conservation, they won’t be able to make use of them and solve problems. Contents of conducted researches are only valuable when they are used to resolve problems and this cannot be achieved without awareness of their existence.

CHAPTER FIVE

CONCLUSIONS AND RECOMMANDATIONS

5.1 Conclusions

The general objective of the study was to assess the impact of agroforestry on soil conservation in Gatsibo District, Rwanda. Based on objectives, the following conclusions were drawn from findings of this study:

Hundred percent of respondents practice at least one system of agroforestry on their farm. Home garden, Live fences around farms and Silvo-pasture are the common and most frequent agro forestry systems in the study area (94.4 % of respondents from Kiramuruzi Sector with the same trend for other two study Sectors). Fodder trees were found to be the most common and frequents reported by 94.4%, 85.4% and 81.25% of respondents from Kiramuruzi, Kabarore and Gasange Sectors Respectively, followed by fruit trees and timber trees.

The majority of respondents adopted modern agroforestry mainly because of the many benefits that it provided believing that Agroforestry contributed to soil conservation in terms of reduced soil erosion, improved soil fertility and improved biodiversity. A hundred percent of respondents in all study Sectors benefited from agroforestry in terms of fodders and energy supply."Reduced soil erosion" is perceived as the most important contribution to soil conservation, mentioned by 100% of respondents In Gasange and Kiramuruzi Sectors and the improvement of tree cover was the most frequent mentioned by 100% of respondents from Kiramuruzi Sector as the way that agroforestry contributes to soil erosion control.

Agroforestry contributes to biodiversity maintenance by the introduction of new species as mentioned by 100% of respondents in all study Sectors, followed by conservation trees species, improved vegetative cover, reduced deforestation and the improved animal diversity Therefore, this study concluded that maintaining diversity in approaches to management of agroforestry systems, along with a pragmatic, unidiomatic view on natural resource management, will provide the widest range of options for adapting to changing economic, social, and climatic conditions.

The majority of respondents in all study Sectors are not aware enough about soil conservation practices in general and agroforestry in particular. Awareness was found to be positively correlated to the adoption of soil conservation practices. The conclusion is that farmers who were more aware of an erosion problem were more likely to adopt conservation measures. About 70% of respondents believe that researches on agro forestry are needed. Only 20% of respondents responded by "yes" to the question asking if there were any existing research findings on the role of agroforestry in soil conservation.

The findings followed the same trend in the three study Sectors and the overall conclusion is that agroforestry has the potential to make a major contribution to soil conservation and sustainable land use. Appropriate agroforestry systems control erosion, maintain soil organic matter and physical properties, and promote efficient nutrient cycling. There is a considerable potential for soil conservation through agroforestry, both in control of erosion and by other means of maintaining soil fertility. This potential applies to many agroforestry practices and over a wide range of climatic zones and soil types.

Agroforestry systems are highly complex, involving the interactions of at least two plant components with each other and with climate and soil. Rural extension agents and farmers need advice on what tree species are appropriate to plant, in what number and arrangement, and with what management practices. Locally conducted trials of prototype systems, on-farm as well as on station, are the level of research, which directly precedes such advice.

Previous researches may have been conducted but residents are not aware of their existence. This is a serious challengebecause, if the District environmental officers and Sector officers, communities, NGOs, associations, private companies and advisers do not understand various benefits of agroforestry and its contribution to soil conservation. Contents of conducted researches are only valuable when they are used to resolve problems and this cannot be achieved without awareness of their existence.

5.2 Recommendations

This research concluded that appropriate agroforestry systems control erosion, maintain soil organic matter and physical properties, and promote efficient nutrient cycling. To fulfill the basic demands of forest resources programs for the planting and management of farm trees, better access to seedling, extension program and training activities should be conducted for the poor farmers.

The findings of this study indicate that Agroforestry has potential to be an effective and efficient biodiversity conservation approach. It is observed that adopting the protective or passive management and fulfilling only subsistence need, has contributed to the conservation of biodiversity and rehabilitation of the ecosystem. However, to maintain this trend in the future also, there is need to address local needs and provide additional benefits.

This study showed that **a**groforestry provides all types of forest products for meeting needs of households. But only few households adopted high income base agroforestry activities. The recommendation is that it should be extended to all households and need to be supported by government.

Awareness was found to be positively correlated to the adoption of soil conservation practices and this research recommends. The findings of this research showed that there are still gaps in our knowledge of agroforestry which require further research. Considering the nature of agroforestry future efforts should be directed at participating on- farm research. This would involve farmers and researchers working together to identify research problems or disseminate research results. Once they are involved and consulted on matters affecting them, farmers will consider themselves partners in success or failure. This approach is likely to minimize the fear of failure by researchers and encourage them to conduct more on-farm research.

REFERENCES

Ainslie, S. R. (1935). *Soil Erosion in Nigeria*. Kaduna, Nigeria Government Printers.

Atangana A., Khasa D., Chang S., and Degrande, A. (2013). Tropical Agroforestry. *Springer Science & Business Media 2(5),* 380 – 395.

Atta-Krah, A. N. and Sumberg, J. E. (1988). *Studies with Gliricidia sepium for Crop/livestock Production Systems in West Africa; Agroforestry Systems.* Ibadan, Nigeria, Martinus Nijhoff/ Dr. W. Junk Publishers.

Baumer, M. (1987). *Agroforesterie et Desertification.* Wagcningen, Netherlands: Centre Technique de Cooperation Agricole et Rurale.

Bichier, P. (2006). *Agroforestry and Maintenance of Biodiversity.* Washington DC: American Institute of Biological Sciences.

Benge, M. (1979). *Use of Leucaena for Soil Erosion Control and Fertilization.* Washington DC: National Academy Press.

Bene, J., Beall, H. W., and Cote, A. (1977). *Trees, Food and People.* Ottawa: International Development Research Centre.

Bojo. J. (1986). *A Review of Cost-benefit Studies of Soil and Water Conservation Projects.* Iowa: Soil and Water Conservation Society.

Bucagu C., Vanlauwe, B. Van Wijk, M. T., and Giller, K. E. (2013). *Assessing Farmers' Interest in Agroforestry in Two Contrasting Agro-Ecological Zones of Rwanda*. *Springer Science & Business Media, 7(3),* 141-158.

Current D., Lutz E., and Scherr, J. S. (1995). *Costs, Benefits, and Farmer Adoption of Agroforestry: Project Experience in Central America and the Caribbean,* Washington DC: World Bank Publications.

Dijkman, M. J. (1950). *Leucaena, a Promising Soil Erosion Control Pant*; *Economic Botany*. Florida: University of Miami.

Dregne. H. E. (1987). *Soil erosion: cause and effect; Land Use Policy*. Amsterdam: Elsevier Ltd.

Dumsday. R. G. and Flinn, J. C. (1977). *Evaluating Systems of Soil Conservation Through Bbio-economic Modelling*. In D. J. Greenland and R. Lai, eds. So/7 *Conservation and Management in the Humid Tropics.* Chichester: Wiley & Sons.

El-Swaify, S. A., Walker, T. S. and Virmani. S. M. (1984). *Dryland Management Alternatives and Research needs for Alfisolsin; the Semi-arid Tropics.* Hyderabad: ICRISAT.

FAO, (2010). Conservation Agriculture, Agriculture and Consumer Protection Department, (Pdf). Rome. Retrieved on 22nd May 2015 through the Food and Agriculture Organization of the United Nations from: http://www.fao.org/ag/ca/.

FAO, (1984). Land Evaluation for Forestry. FAO Forestry Paper 48. Rome, Italy.

Greenland, D. J. and Lai R. (1977). *Soil Conservation and Management in the Humid Tropics.* Chichester: Wiley & Sons.

Fergus, L. Sinclair. (2013). Agroforestry: Science, Policy and Practice: Selected papers from the Agroforestry Sessions of the IUFRO 20th World Congress, Tampere, Springer Science & Business Media, Finland.

Habyarimana, L. (2011). Challenges Facing Students and Teachers of Nine years Basic Education in rural areas in Rwanda, Case of Rulindo district. B.Sc, Kigali Institute of Education. Kigali, Rwanda.

Hailey L. (1938). *An African Survey*. London: Oxford University Press.

Hardy, F. (1942). Soil erosion in Trinidad and Tobago. *Trop Agric 19(2),* 29-35

Hobbs, S. E., Jensen, D. B., and Chapin, F. S., (1993). *Resource Supply and Disturbance as Controls Over Present and Future Plant Diversity*. Berlin: Springer Berlin Heidelberg.

Hudson, N. W. (1983). Soil Conservation Strategies in the Third World. *Journal of Soil and Water Conservation. 38(10),* 446-50.

ICRAF, (1989). *Viewpoints and Issues on Agroforestry and Sustainability*. Nairobi: University of Minnesota.

ICRAF, (1985), Working paper, Issues 37-45.Nairobi, International Council for Research in Agroforestry. Nairobi, Kenya.

ICRAF, (1987a), *The Potential of Agroforestry for Soil Conservation: A Predictive Model. Soil changes under agroforestry*. Nairobi, International Council for Research in Agroforestry.

ICRAF, (1987b), *The Role of Agroforestry in the Farming Systems in Rwanda with Special Reference to the Bugesera-Gisaka-Migongo (BGM) Region*. Nairobi: International Council for Research in Agroforestry.

Kumar B. M. and Nair P. K. R. (2013). *Carbon Sequestration Potential of Agroforestry Systems: Opportunities and Challenges.* New York, Springer Science & Business Media.

Lal, R. (1985), *SoilErosion and Its Relation to Productivity in Tropical Soils.* In S.A. El-Swaify,W.C. Moldenhauer and A. Lo, eds. *Soil erosion and conservation.* Ankeny, Iowa: FAO.

Lundgren, L. (1980), *Comparison of Surface Runoff and Soil loss From Runoff Plots in Forest and Small-scale Agriculture in the Usambara Mountain, Tanzania*. Sweden. Wiley & Sons.

Lundgren, B. O., and J. B. Raintree, (1982), Sustained Agroforestry. In B. Nestel (ed.) Agricultural Research for Development: Potential and Challenges in Asia. ISNAR, The Hague, Netherlands. 37 - 49.

Mapes, J. J. (1862), *Working Farmer, Volume 14*. New York, Cornell University.

Mathur, II. N., Agarwal, M. C.. Babu, R. and Joshie, P. (1979). Benefit-Cost Ratio of Fuel CumFodder Plantation in Doon Valley. *Indian Journal of Soil Conservation. 7(2),* 53-58.

Nair, P. K. R., (1989). *Agroforestry Systems in the Tropics.* Dordrecht, the Netherlands: Kluwcr,

NISR Rwanda, (2010), *EICV3 District Profile - East – Gatsibo District*. Kigali: National Institute of Statistics of Rwanda.

Ochola, O. Washington, Sanginga P. C., and Bekalo I. 2010. *Managing Natural Resources for Development in Africa: A Resource Book.* Ottawa, International Development Research Centre.

Peake, E. (1986). Erosion, Crop yields and Time: A Reassessement of Quantitative Relationships. Discussion Paper 191. University of East Anglia. School of Development Studies. Norwich, UK

Raintree, J. B. (1987). *User's Manual: An Introduction to Agroforestry Diagnosis and Design*. Nairobi: ICRAF.

REMA, (2009). Rwanda State of Environment and Outlook Report, Kigali, Rwanda Environment Management Authority.

REMA, (2010). *Integrated Management of Critical Ecosystems (IMCE)*. Kigali, Rwanda Environment Management Authority.

RNRA, (2012). Water Quality Monitoring in Rwanda. Report III: October - November 2012 Kigali, Rwanda.

Roose, E. (1980), *Dynamique Actuelle d'un Sol Ferrallitique Sablo-argileux; Ires Desaturé sousCultures el Sousjoret Dense Humide Equatoriale du Sud de la Cote d'lvoire*. Paris: ORSTOM.

Roose, E. (1988), *Soil and Water Conservation Lessons from Steep-Slope Farming In French speaking Countries of Africa*. In W.C. Molden haucrand N.W. Hudson, cds. *Conservation farming on steep lands* . Ankeny, Iowa: Soil and Water Conservation Society.

Rose, C. W. (1988), *Research Progress on Soil Erosion Processes and a Basis for Soil Conservation Practices*. In R. Lai, ed. *Soil erosion research methods*. Ankeny. Iowa: Soil andWater Conservation Society.

Nair, P. K. R., (1993), *An Introduction to Agroforestry*. Boston: Kluwer.

Sanchez, PA. (1976), *Properties and Management of Soils in the Tropics*. New York: Wiley & Sons.

Sanchez. P A. (1987), *Soil Productivity and Sustainability in Agroforestry Systems*. In H.A. Stepplerand P.K R Nair, eds. *Agroforestry: a Decade of Development*. Nairobi: ICRAF.

Sheng, T .C. (1986). *Watershed Conservation: a Collection of Papers for Developing Countries*. Fort Collins, Colorado: Colorado State University.

Shaxson. T. F., Hudson. N. W., Sanders, D.W.. Roose, E. and Moldenhauer, W. C. (1989). *Land Husbandry*. *A Framework for Soil Water Conservation.* Ankeny, Iowa: Soil and Water Conservation Society.

Siderius, W., (1986), *Fund Evaluation for Land-Use Planning and Conservation in Sloping Areas*. ILR1 Publication. Wageningen, Netherlands.

Singh, G., Ventakataramanan. C. and Sastry, G. (1981), *Manual of Soil and Water Conservation Practices in India*. Dehra Dun, India: Central Soil and Water Conservation Research and Training Institute.

Stockdale, F. A. (1937), Soil Erosion in the Colonial Empire. *Empire Journal of Experimental Agriculture*, 5(20), 123 – 423.

Stocking, M. (1986), *The Cost of Soil Erosion in Zimbabwe in Terms of the Loss of Three Major Nutrients.* Consultants Working Paper 3. Rome, Italy.

Stocking, M. A. (1988), *Assessing Vegetative Cover and Management Effects*. In R. Lai, ed.*Soil Erosion Research Methods.* Ankeny, Iowa, USA: Soil and Water Conservation Society.

UNESCO, (2002), *Best Practices Using Indigenous Knowledge*. Paris: UNESCO.

USAID, (2005), *Environmental Guidelines for Small-Scale Activities in Africa: Environmentally Sound Design for Planning and Implementing Development Activities.* Washington DC: The United States Agency for International Development.

Wiersum, K. F. (1985), *Effects of Various Vegetation Layers in An Acacia Auriculiformis Forest Plantation on Surface Erosion in Java, Indonesia.* Ankeny, Iowa: Soil Conservation Society of North America.

Wiggins. S. L. (1981), *Theeconomics of Soil Conservation in the Achelhuate River Basin*. El Salvador. In R.P.C. Morgan, ed. *Soil conservation: problems and prospects.* Chichester : Wiley & Sons.

Yost, R. S., El-Swaify, S. A., Dangler, E. W. and Lo, A. (1985), *The Influence of Simulated Soil Erosion and Restorative Fertilization on Maize Production on an Oxisol.* Ankeny, Iowa: Water Conservation Society.

Young, A., (1987). *Traditional Forms of Land Use in Relation to Soil Erosion*. In *Soil Conservation and Management in Developing Countries.* FAO Soils Bulletin 32. Rome: FAO, 51-59.

Young, A., (1989). *Agroforestry for Soil Conservation.* Wallingford: International Council for Research in Agroforestry (ICRAF).

Young, A. (1997). *Agroforestry for Soil Management*. Nairobi: University of Minnesota.

Young, A. and Saunders L., (1986). *Rates of Surface Processes and Denudation.* Boston, Oxford University Press.

APPENDICES

Appendix 1: Questionnaire Survey

I. Questionnaire filled by household's heads

I am **Deus Muhirwa**, a Masters Candidate in Environmental Management at Open University of Tanzania. As a part of my dissertation, I am doing a research on the contribution of agroforestry in soil conservation in Gatsibo District, Eastern Rwanda. Some information can only be provided by residents. I would be really thankful if you could spend some time, taking part of this survey. This will take you no more than 10 min.

Everything mentioned in the survey is just for the academic study and your answers will only be used for the research purposes.

Thank You,

Deus Muhirwa

General information

a. Date ____

b. Respondent name ______________________ Sex _____ Age _____ Signature _____

c. District ____________ Sector _______________ Cell_________ Village __________

d. Marital status (a) Single ____ (b) Married ____ (c) Divorced ____ (d) Widow____

e. Sex ______ Age _____ Education level ___________ Occupation ________

f. House hold relation code: (a) Household head (b) Wife (c) Son/daughter (d) Servant

g. House Hold Size: (a) 1 (b) 1-5 (c) 5-10 (e) More than 10

h. Income sources: (a) Agriculture (b) Business (c) Service (e) Labor (f) Any other

1. What is the size of your land?

    1. Less than 1Ha
    2. 1 to 3Ha
    3. More than 3 Ha

2. Are you practicing any agroforestry system?

    1. YES
    2. NO

If YES

What are the agroforestry systems found on your farm?

1. Home garden (*Agrohortisiviculture*) systems
2. Live fences around farmlands
3. Trees in and around the Agricultural Fields
4. Silvo-pasture system
5. Agrisilvicultural System
6. Agroforestry species for green manure

3. *Which type of trees would you most likely use your best land to grow?*

1. Food crop

2. Cash crop

3. Tree crop ….

4. What are the best-suited combination of trees and crops in your land?

1. Timber tree
2. Fruit tree
3. Fodder tree
4. Other (Medicine, shrubs, Grass etc.)

5. What were your reasons to adopt agroforestry?

1. Agroforestry products
2. Erosion control
3. Sustainable agriculture
4. Family income

6. Does agroforestry contribute to soil conservation?

1. YES
2. NO

If YES, How can agroforestry contribute to soil conservation?

1. Reduced soil erosion
2. Improved soil fertility& productivity
3. Improved biodiversity

7.Does agroforestry contribute to soil erosion control?

1. YES
2. NO

If YES, How can agroforestry contribute to soil erosion control?

1. Availability of pasture
2. Reduced deforestation
3. Permanent soil cover
4. Wind and runoff breaking
5. Improved tree diversity

8. Does agroforestry contribute to soil fertility?

1. YES
2. NO

If YES, How can agroforestry contribute to soil fertility?

1. Reduced Soil erosion
2. Soil cover improvement
3. Improved soil properties
4. Others

9. Does agroforestry contribute to soil productivity?

1. YES
2. NO

If YES, How can agroforestry contribute to soil productivity?

1. Fodders and energy supply
2. Overall family income
3. Rural needs fulfillment
4. Increase of yields

10. Does agroforestry contribute to biodiversity maintenance?

1. YES
2. NO

If YES, How can agroforestry contribute to biodiversity maintenance?

1. Introduction of new species
2. Conservation of tree species on farms
3. Improved vegetative cover
4. Reduced pressure on forests
5. Improved animal diversity

11. What is your awareness level in agroforestry and soil conservation

1. HIGH
2. MODERATE
3. LOW

12. Has been there any training on the role played by agroforestry in soil conservation?

4. YES
5. NO

13. Has been there any research on Agroforestry before in your community?

1. YES

2. NO

If YES, do you know what were the findings?

14. Do you thing researches on soil conservation in general and agroforestry in particular are necessary?

1. YES
2. b. NO

17. What are the Problems related Agroforestry practices?

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…………………………………………………………………………………………

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24. What would you recommend to the government so as to enhance technology transfer and subsequent adoption in the district?

CHECK LIST FOR INTERVIEWING KEY INFORMANTS

I am **Deus Muhirwa**, a Masters Candidate in Environmental Management at Open University of Tanzania. As a part of my dissertation, I am doing a research on the contribution of agroforestry in soil conservation in Gatsibo District, Eastern Rwanda. Some information can only be provided key informants. I would be really thankful if you could spend some time, taking part of this survey. This will take you no more than 10 min.

Everything mentioned in the survey is just for the academic study and your answers will only be used for the research purposes.

Thank You,

Deus Muhirwa

Date: ______________________________

Respondent name ______________________ Sex _____ Age _____ Signature _____

District ____________ Sector _______________ Cell_________ Village __________

Position ______________ Study level ____________________

1. What are the social, economic, political, legal and institutional challenges in agroforestry practice adoption?
2. What are the perceived effects of agroforestry on soil conservation?
3. Which actions can be taken to increase the extent of agroforestry practices?
4. What can be done to ensure a guarantee for the farmers and strengthen their willingness to introduce new species?
5. What can be done to extend high income base agroforestry activities to all households?

Appendix 2: Table Presentation of the Findings

Table 1: Agroforestry Practices (Young, 1989)

MAINLY AGROSYLVICULTURAL	Rotational	Shifting cultivation, Improved
	Spatial mixed	Trees on cropland, Plantation
	Spatial zoned	Hedgerow intercropping,
MAINLY OR PARTLY SYLVOPASTORAL	Spatial mixed	Trees on rangeland or pastures Plantation crops with pastures
	Spatial zoned	Live fences, Fodder banks
TREE COMPONENT PREDOMINANT		Woodlots with multipurpose management, Reclamation forestry leading to multiple use
OTHER COMPONENTS		Entomoforestry, Aquaforestry

Table 2: Target Population

Sector	Population	Households*
Kabarore	50,411	6300
Kiramuruzi	21,830	2728
Gasange	17,758	2220
Total	**89999**	**11248**

Source: Gatsibo DDP, 2012.

*The number of HH is obtained by dividing the total population by 8 which is the average number of HH members

Table 3: Final and Total Adjusted Sample Size

Sectors	Total Population	Households (N)	Sample (n x N/N+n)	Purposed Key informants	Final and total adjusted sample size
Kabarore	50,411	6300	38	3	
Kiramuruzi	21,830	2728	16	2	
Gasange	17,758	2220	14	2	
Total	**89999**	**11248**	**68**	**7**	**75**

Table 4: Age Distribution of Households' Heads

Age range	Number			Percentage		
	Kabarore	***Kiramuruzi***	***Gsange***	***Kabarore***	***Kiramuruzi***	***Gsange***
18-25	14	6	5	18.7	8	6.7
26-35	11	4	6	14.7	5.3	8
36-50	9	4	3	12	5.3	4
51-Above	7	4	2	9.4	5.3	2.7
Total	**41**	**18**	**16**	**54.7**	**23.9**	**21.4**

Table 5: Gender Status of Respondents

Households' heads	Gender distribution						Total
	Male			Female			
	Kabarore	Kiramuruzi	Gasange	Kabarore	Kiramuruzi	Gasange	
Number	21	12	11	20	6	5	**75**
Percentage per Sector	51.4	64	66.6	48.6	36	33.4	**100**

Table 6: Education Status among Respondents

Households' heads	Education status									Total
	Illiterate			Basic Level			High level			
	Kabarore	Kiramuruzi	Gasange	Kabarore	Kiramuruzi	Gasange	Kabarore	Kiramuruzi	Gasange	
Number	20	9	9	19	8	5	**2**	**1**	**2**	**75**
Percentage per Sector	48.5	52	53.4	45.5	44	33.4	**6**	**4**	**13.2**	**100**

Table 7: Income per Month per Household

Income sources	Sectors	Number per Sector	Percentage per Sector	Total Number	Total Percentage
Agriculture	Gasange	9	56.25	**33**	**44**
	Kabarore	16	39.1		
	Kiramuruzi	8	44.5		
Business	Gasange	1	6.25	**15**	**20**
	Kabarore	9	21.9		
	Kiramuruzi	5	27.8		
Service	Gasange	2	12.5	**10**	**13.3**
	Kabarore	5	12.2		
	Kiramuruzi	3	16.7		
Labor	Gasange	3	18.75	**10**	**13.4**
	Kabarore	5	12.2		
	Kiramuruzi	2	11.1		
Any other	Gasange	1	6.25	**7**	**9.3**
	Kabarore	6	14.6		
	Kiramuruzi	0	0		
Total				75	100

Table 8: Farm size Distribution in the Study Area

Farm Size	Sectors	Number per Sector	Percentage per Sector	Total Number	Total Percentage
	Gasange	3	18.75		
	Kabarore	18	43.9		
≤1	Kiramuruzi	5	27.8	**26**	**34.7**
	Gasange	8	50		
	Kabarore	18	43.9		
1 to 2	Kiramuruzi	11	61.1	**37**	**49.2**
	Gasange	5	31.25		
	Kabarore	5	12.2		
≥3	Kiramuruzi	2	11.1	**12**	**16.1**
Total				**75**	**100**

Table 9: Major Agroforestry Systems and Practices in Study Area

Major Agroforestry Systems and Practices	Sectors	Frequency per Sector	Percentage per Sector	Overall Frequency (N/75)	Total Percentage
Home garden	Gasange	14	87.5		
	Kabarore	36	87.8		
	Kiramuruzi	17	94.4	**66**	**88**
Live fences around farmlands	Gasange	11	68.75		
	Kabarore	34	82.9		
	Kiramuruzi	17	94.4	**62**	**82.6**
Silvo-pasture system	Gasange	11	68.75		
	Kabarore	34	82.9		
	Kiramuruzi	17	94.4	**62**	**82.6**
Trees in and around the Agricultural Fields	Gasange	10	62.5		
	Kabarore	30	73.2		
	Kiramuruzi	15	83.3	**55**	**73.3**
Agrisilvicultural System	Gasange	11	68.75		
	Kabarore	28	68.3		
	Kiramuruzi	14	77.8	**53**	**70.6**
Agroforestry species for green manure	Gasange	2	12.5		
	Kabarore	10	24.3		
	Kiramuruzi	8	44.4	**20**	**20.6**
Total				75	100

Table 10: Tree Species Diversity in the Study Area

Trees types	Sectors	Frequency per Sector	Percentage per Sector	Overall Frequency (N/75))	Total Percentage
Fodder tree	Gasange	13	81.25		
	Kabarore	35	85.4		
	Kiramuruzi	17	94.4	**65**	**86.6**
Fruit trees	Gasange	13	81.5		
	Kabarore	34	82.9		
	Kiramuruzi	17	94.4	**64**	**85.4**
Timber Trees	Gasange	11	68.75		
	Kabarore	21	51.2		
	Kiramuruzi	9	50	**41**	**54.7**
Other	Gasange	2	12.5		
	Kabarore	11	26.8		
	Kiramuruzi	4	22.2	**17**	**22.7**

Table 11: Motivation for Adopting Agroforestry

Reasons to Adopt Agroforestry	Sectors	Frequency per Sector	Percentage per Sector	Overall Frequency (N/75)	Total Percentage
Agroforestry products	Gasange	15	93.75	**72**	**94.6**
	Kabarore	40	97.6		
	Kiramuruzi	17	94.4		
Erosion control	Gasange	15	93.75	**71**	**94**
	Kabarore	39	95.1		
	Kiramuruzi	17	94.4		
Sustainable agriculture	Gasange	10	62.5	**56**	**74.6**
	Kabarore	32	78		
	Kiramuruzi	14	77.8		
Family income	Gasange	11	68.75	**55**	**73.3**
	Kabarore	30	73.2		
	Kiramuruzi	14	77.8		
Other	Gasange	2	12.5	**10**	**13.4**
	Kabarore	5	12.2		
	Kiramuruzi	3	16.7		

Table 12: The Perceived Role of Agroforestry in Soil Conservation

The way	Sector	Frequency per Sector	Percentage per Sector	Overall Frequen	Total Percenta
Reduced soil erosion	Gasange	16	100		
	Kabarore	40	97.6		
	Kiramuruzi	18	100	**74**	**98.6**
Improved soil fertility& productivity	Gasange	15	93.75		
	Kabarore	39	95.1		
	Kiramuruzi	17	94.4	**71**	**94.7**
Improved biodiversity	Gasange	12	75		
	Kabarore	34	82.9		
	Kiramuruzi	16	88.9	**62**	**82.6**

Table 13:The Perceived contribution of Agroforestry t Soil Erosion Control

The way	Sector	Frequency per Sector	Percentage per Sector	Overall Frequency (N/75)	Total Percentage
Improved tree diversity	Gasange	14	87.5	71	94.6
	Kabarore	39	95.1		
	Kiramuruzi	18	100		
Wind and runoff breaking	Gasange	16	100	69	92
	Kabarore	35	85.4		
	Kiramuruzi	18	100		
Reduced deforestation	Gasange	12	75	62	82.6
	Kabarore	32	78		
	Kiramuruzi	18	100		
Permanent soil cover	Gasange	14	87.5	62	82.6
	Kabarore	33	80.5		
	Kiramuruzi	15	83.4		

Table 14: The perceived Contribution of Agroforestry to soil Fertility Improvement

The way	Sectors	Frequency per Sector	Percentage per Sector	Overall Frequency (N/75)	Total Percentage
Reduced Soil erosion	Gasange	16	100	70	98.4
	Kabarore	37	90.2		
	Kiramuruzi	17	94.4		
Soil cover	Gasange	13	81.2	70	93.3
	Kabarore	40	97.5		
	Kiramuruzi	17	94.4		
Improved soil properties	Gasange	11	68.75	62	82.6
	Kabarore	37	90.2		
	Kiramuruzi	14	77.8		
Other	Gasange	9	56.25	40	53.3
	Kabarore	20	47.8.		
	Kiramuruzi	11	61.1		

Table 15:Perceived Agro forestry's Benefits of Improved Soil Productivity

Benefits	Sectors	Frequency per Sector	Percentage per Sector	Overall Frequency (N/75)	Total Percentage
Fodders and energy supply	Gasange	16	100	**75**	**100**
	Kabarore	41	100		
	Kiramuruzi	18	100		
Overall family incom	Gasange	15	93.75	**72**	**96**
	Kabarore	41	100		
	Kiramuruzi	16	88.9		
Rural needs fulfillment	Gasange	12	75	**55**	**73.3**
	Kabarore	28	68.3		
	Kiramuruzi	15	83.4		
Increase of yields	Gasange	10	62.5	**50**	**66.7**
	Kabarore	28	68.3		
	Kiramuruzi	12	66.7		

Table 16: Perceived Agroforestry's Benefits of Biodiversity Maintenance

Benefits	Sectors	Frequency per Sector	Percentage per Sector	Overall Frequency (N/75)	Total Percentage
Introduction of new species	Gasange	16	100	**75**	**100**
	Kabarore	41	100		
	Kiramuruzi	18	100		
Conservation of tree	Gasange	15	93.75	**74**	**98.6**
	Kabarore	41	100		
	Kiramuruzi	18	100		
Improved vegetative cover	Gasange	14	87.5	**69**	**92**
	Kabarore	38	92.7		
	Kiramuruzi	17	94.4		
Reduced pressure on forests	Gasange	12	75	**62**	**82.6**
	Kabarore	35	85.4		
	Kiramuruzi	15	83.4		
Improved animal diversity	Gasange	15	93.75	**60**	**80**
	Kabarore	31	75.6		
	Kiramuruzi	14	77.8		

Table 17: Table of Alain BOUCHARD

	Precision								
	90 times by100			95 times by 100			99 times by 100		
	10%	5%	1%	10%	5%	1%	10%	5%	1%
Infinity	68	271	6765	96	384	9604	166	664	16589
1000000	68	271	6720	96	384	9513	166	663	16319
100000	68	270	6336	96	383	8763	166	659	14229
50000	68	269	5959	96	381	8057	165	655	12457
10000	67	263	4035	95	370	4899	163	622	6239
5000	67	257	2875	94	357	3288	161	586	3842
1000	63	213	871	88	278	906	142	399	943
500	60	176	466	81	271	475	125	285	485
100	41	73	99	49	80	99	63	67	99
50	29	43	50	33	44	50	49	47	50

Source: HABYARIMANA Ladislas (2012)