ROLES OF GRASSLANDS IN SUSTAINABLE IMPROVEMENT OF LAND PRODUCTIVITY IN BUKOBA DISTRICT, TANZANIA

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A THESIS SUBMITTED IN FULFILLMENT FOR THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY OF THE OPEN UNIVERSITY OF TANZANIA

2015

CERTIFICATION

The undersigned certifies that they have read the thesis and hereby recommends for acceptance by the Open University of Tanzania the thesis entitled: **“Roles of grasslands in sustainable improvement of land productivity in Bukoba District, Tanzania”,** in fulfillment of the requirements for the degree of Doctor of Philosophy.

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DECLARATION

I, **Amos Ndamwesiga Mwijage**, do hereby declare that this study is my own work and that it has not been presented and will not be presented to any other University for a similar or any other degree award.

Signature………………………………..

Date……………………………………..

DEDICATION

This Thesis is dedicated to my beloved Late father Ta Cornel (1903-1992), my Late mother Ma Lydia (1924 – 2012) and to my Late sister Martina (1950-2008) who invested tirelessly for my schooling but unfortunately passed away before completion of my career crest. May Almighty God let their Souls rest in eternal peace, Amen.

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Indeed, I attribute the accomplishment of this work to the support and contributions of many people and institutions that was instrumental and I would like to thank them all, but the space is also limited. Understandably, it is not easy to mention all in just few paragraphs, so should your name fall missing, just know that I do appreciate your valuable contributions that facilitated this work come to reality.

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ABSTRACT

This study was conducted in Bukoba District where land shortage and poor soil fertility are predominant thus limiting the productivity of the land. In this farming system, grasslands form an integral part in land productivity. However, changes in land tenure systems particularly for grasslands in recent years have undermined the functionality of the agro-ecological system. This study was designed to explore the roles of grasslands in sustainable improvements of land productivity through intensification of three predominant land use types namely *Kibanja*, *Kikamba*, and *Rweya*. Research methods involved interviews, group discussions, and retrieval of archival information on changing tenure systems; field experimentation and model development. Data were analysed for descriptive statistics, principal component analysis, ANOVA and modelling by SPSS, Conoco, GENSTAT and GAMS, respectively. Results established that customary tenure and land use practices have been destabilized by changes aimed at privatization of grasslands. Characterisation of farming households revealed three virtual farm types (FT) distinguished by: soil fertility management strategies, food security, and farm and off-farm income being important indicators of variability. All FT were found to be net food buyers annually. Grassland productivity revealed annual biomass production of 7.4 t ha^{-1} and 7.1 t ha^{-1} at high and low rainfall zones, respectively. The nutritive qualities of grasses were generally low throughout measurement period, although was better during first six months after burning implying the best grazing phase. Sustainability options for the three virtual FT showed that *Kibanja* productivity can be maintained in the absence of cattle provided that sufficient area of *Kikamba* to grow herbaceous legumes for supplying adequate N and K for optimum *Kibanja* productivity. Farm labour were found amounting to only 35%, 25%, and 39% of the available family labour for FT1, FT2, and FT3, respectively, implying presence of excess labour that could be allocated to off-farm activities. These findings imply that the productivity of *Kibanja* could be sustained even in absence of cattle provided there is sufficient land area for *Rweya* and *Kikamba* accessible to farming households.

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LIST OF ABBREVIATIONS

AIDS:	Acquired Immune Deficiency Syndrome
ANOVA:	Analysis of variance
ESRF:	Economic and Social Research Foundation
FAO:	Food and Agriculture Organization of the United Nations
FSRP:	Farming Systems Research Program
GAMS:	General Algebraic Modelling Systems
GDP:	Gross Domestic Product
HIV :	Human Immunodeficiency Virus
HRZ:	High Rainfall Zone
INIBAB:	International Network for the Improvement of Banana and Plantain
KCDP:	Kagera Community Development Program
LRZ:	Low Rainfall Zone
MAFC:	Ministry of Agriculture Food Security and Cooperatives
MALD:	Ministry of Agriculture and Livestock Development
NBS:	National Bureau of Statistics
NLP:	National Land Policy
SPSS:	Statistical Package for the Social Sciences
SSA:	Sub-Saharan Africa
UNAIDS:	Joint United Nations Programme on HIV/AIDS

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background

Despite the fact that sub-Saharan Africa (SSA) is relatively well endowed with natural resources, this region has the lowest land and labour productivity in the world (Mwangi, 1997). While the population growth rate is among the highest in the world with average of 3 percent per year, the annual increase in food production is only 2 percent (Breman and Debrah, 2003). At the same time, poverty is at increasing trend, while the policy on economic and institutional environment in these countries still does not create the necessary incentives for improved agricultural productivity per unit area (FAO and World Bank, 2006). The major challenging task therefore is to promote a balanced and efficient use of natural resources including land and its resources at farm and community levels in order to intensify agriculture production in a sustainable manner.

Tanzania is one of the countries in SSA located in East Africa, with an area of 945,087 sq km, and a population of 45 Million inhabitants (NBS, 2013). The economy is largely based on agriculture, which accounts for more than half of GDP, providing approximately 85% of exports, and employing about 80% of rural workforce. The topography and climatic conditions, however, limit cultivated crops to only 4% of the land area (ESRF, 2006). More than 80% of the population is rural and almost a half of country population is under 15 years (NBS, 2013).

Kagera is one of 30 regions in Tanzania having eight administrative Districts among which are Bukoba, located on the North-Western Tanzania along the shore of Lake Victoria (Figure 1). Main economic activities in the District and the region as whole include agriculture (crop and livestock production), fisheries, and off-farm small business. In Bukoba District agriculture employs about 90% of the rural population (Mwijage *et al*. 2009). Main crops are: highland banana (*Musa* spp L., 33% of the total farm area), Robusta coffee (*Coffea canephora* Pierre ex A. Froehner, 22%), and common beans (*Phaseolus vulgaris* L, 15%). The roots and tubers (cassava - *Manihot esculenta* Crantz, and sweet potato - *Ipomoea batatas* (L.) Lam occupy 22% and the remaining crops such as fruit trees, spices, pumpkins (*Cucurbita pepo* (L.) Dumort, yams (*Discorea sp*) Molina, taro (*Colocasia esculenta* (L.) Schott, tomatoes (*Solanum lycopersicum* L.) and amaranths (*Amaranthus* spp. L.) altogether occupy 8%. Other economic activities include small-scale fishing, and off-farm waged labour in the Bukoba municipal and neighbouring institutions.

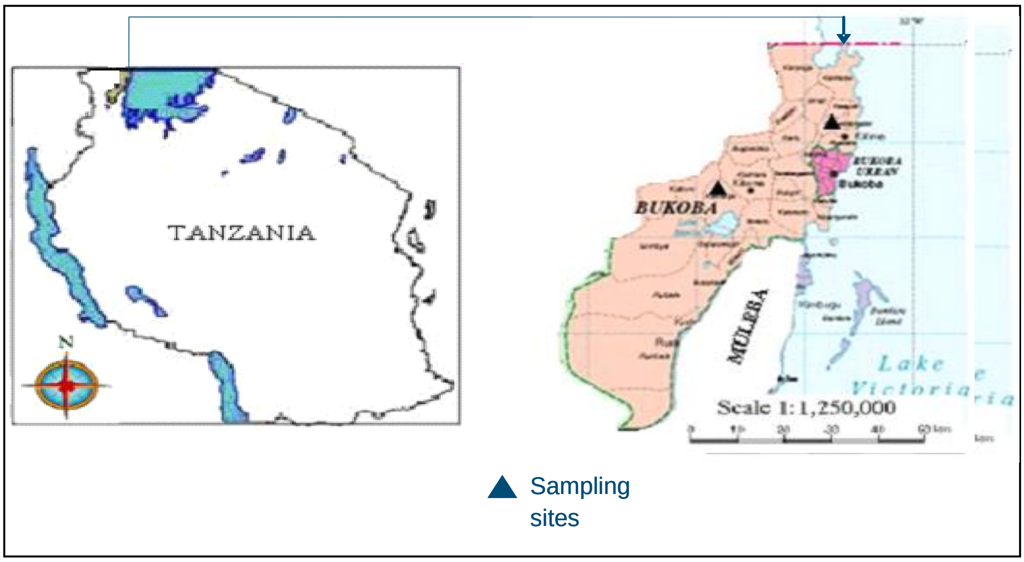


Figure 1: Map of Tanzania showing the location of Bukoba District and villages in which this study was conducted. (31° - 32°E and 1° -1°30'S) (After Shand, 2006)

Past efforts in agricultural research in Bukoba District has focused mainly on production intensification that require purchased farm inputs which, incidentally are beyond reach by most smallholder farmers. Consequently, this has resulted into limited practical results as evidenced by continuously declining land productivity. In order to focus on current gaps and challenges, the global research agenda is gradually moving from center of attention on individual crop commodity-based performance towards improving the productivity of agro ecological system through improving resource use efficiency at farm scale while targeting appropriate technologies across the diverse nature of farming households (Giller *et al*., 2006; Tittonel, *et al.*, 2008).

Availability and access to common land resources

Accessibility to, and availability of common land based resources that impacts on land productivity to smallholder farmers are currently limited to a small number of farmers and is likely to continue like this in future until appropriate programs and policies are put in place. Immediate strategies using farmer-available resources are therefore needed to reach more farmers for alleviating poor productivity problems. Although fertilizers are used in some areas, but are applied in very small quantities and therefore insufficient to meet crop demands Smaling *et al.* (1997). Organic inputs are often proposed as alternatives to mineral fertilizers although traditional materials such as grass mulch, crop residues, and animal manures cannot meet crop nutrient demand over large areas because of limited quantities available, inherent low nutrient content, and the associated high labour demand for processing and application. Accordingly, crop yields still fall short of their potential because of inadequate nutrient inputs. Apparently there is rapid decrease of the area under

Rweya (Figure 3) which is the main sources of organic inputs to farmers thus amalgamate current threats to productivity of the *Kibanja.*

1.2 Characteristics of the Farming System

The farming system in Bukoba District represents a typical East Africa highland banana-coffee-based farming system, considered as one of highly intensive systems in SSA (McMaster, 1961; Baijukya, 2004). Inhabitants are mainly the *Haya* people who makes majority of smallholder farmers. The *Haya* divides their land use into three main functional land-use types namely (for convenience) in local vernacular as (i) *Kibanja*, (ii) *Kikamba*, (iii) *Rweya* (Plates 1 and 2). Here, a land use type is defined not only as the actual cover of the land with vegetation, but also the functional use of the land and the social values attached to different uses.

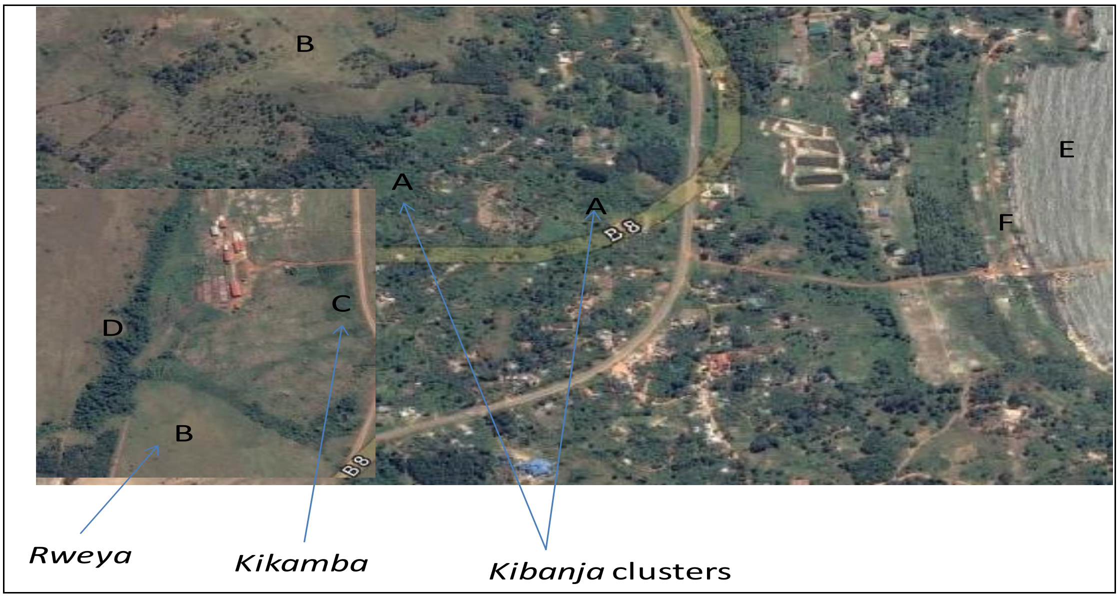


Plate 1: Aerial photograph showing the position of the *Kibanja* (A), the *Rweya* (B), the *Kikamba* (C) river lines with riparian forest (D) and Lake Victoria (E) and other features including beaches (F), on the landscape of Bukoba District (Source: Google Earth, 2014)

The *Kibanja* (plural *bibanja)* is a home garden with mixed-crops but dominated by bananas. So a person is regarded to have *Kibanja* only if he/she has bananas growing around. The *Kibanja* also has dwelling, economic and social importance to the *Haya* community including burying the dead (FSRP, 1990; Maruo, 2002; Yamaguchi and Araki, 2003). A group of *bibanja* of about 1000 households forms a community of a village. Traditionally, the *Haya* people had devoted to bananas as staple food such that they could eat cooked bananas for whole year round if available. Robusta Coffee is grown as main cash crop in mixture with banana in the *Kibanja* sub-system. The *Kibanja* is also mixed with other seasonal crops such as legumes, roots and tubers, vegetables, trees (fruits and timber), spices and local herbs. Often, soil fertility in this land use type is enhanced by cushions of organic materials originating from the *Rweya* grass as mulch, manure, residues from the *Kikamba* and household refuse. This means that Soil fertility management in the *Kibanja* depends not only on inherent natural fertility, but also on the degree of leaching and the availability of organic manure. Generally, the status of soil fertility for the *Kibanja* sub-system is gradually decreasing at the moment following low and yet declining supply of intrinsic and external inputs.

However, Bukoba District is among areas rated to have the highest nutrient mining in Sub-Saharan Africa, with an estimated annual nutrient depletion rate of 41 kg nitrogen (N), 4 kg phosphorus (P) and 31 kg potassium (K) per hectare (Bekunda *et al.*, 2004). These figures represent the balance between nutrient inputs as fertiliser, manure, atmospheric deposition, biological nitrogen fixation, and sedimentation, and nutrient outputs as harvested products, crop residue removals, leaching, gaseous losses, surface runoff and erosion. The figures, therefore, are evidence that nutrient inputs are limited, and the basis of argument that the future growth in agriculture in the region will depend primarily on improved land anagement.

The *Kikamba* is intrinsically a piece of land adjacent to the *Kibanja* ordinarily away from the homestead, with relatively low productivity or a deteriorating *Kibanja* with poor soil fertility status. This land use constitutes a small fallow land with mixed use for growing seasonal crops like maize, sweet potato, cassava and yams. Often, it is generally left to be reclaimed by grass and weeds or to lie fallow. The *Kikamba* continuously exports nutrients to the *Kibanja* via crop residues (Baijukya *et al*., 2005). Several reasons constitute to the formation of the *Kikamba*; for instance, the farm unit may be too large, so that the farmer fails to maintain part of it due to labour constraints, or he/she may be too old thus unable to till the whole *Kibanja*; change of ownership of the farm where it may take some time before the new occupant manages to cultivate the whole farm. This sub-system is sometimes regarded as a sub-type under the *Kibanja* with same tenure arrangements.

The *Rweya* constitute open grassland with several shallow and deep-rooted grass species, few trees and shrubs. This land use type is located between villages (Plate 1), mainly with shallow rock outcrops or steep slope gradients that originally was owned and accessed communally for multiple uses including cultivation of crops, grazing livestock and fodder collection, source of grasses for mulching *Kibanja*, thatching, and collection of grasses for house carpeting, drying sardines, habitat of wild animals and provide places for social functions. It is, therefore an important land use type for the livelihoods of rural communities. However, overall area cover and the productivity of the *Rweya* is rapidly declining due to many factors, including population pressure, unfavorable climate (such as high rainfall, which results in high leaching of soil nutrients) and changes in tenure systems. Other factors comprise lack of awareness of the benefits of soil conservation among *Rweya* users which causes them to continue with same farm practices. Besides, by-laws on the use of the *Rweya* do not give incentives for users to adopt soil conservation measures; therefore the rate of degradation in the *Rweya* is rapidly raising leading to decreased efficiency of entire farming system.

The fertility status of the *Kibanja* has been maintained by continuous importation of nutrients from the *Rweya* in the form of mulch and manure. The *Rweya* has been deemed sufficient to maintain the productivity of the *Kibanja* subsystem for past many years. With time, changes of economic policies since political independence in 1961 to-date have contributed to suppression of the role of traditional rulers in control and management of the *Rweya*. Village governments have continued to have very little regulatory power in the control of *Rweya* use and management. Consequently, there has been shifting of balances among the three dominant and closely interrelated land use types (*Kibanja*, *Kikamba*, and the *Rweya*), thus threatening for continued system productivity.

1.3 Problem statement

The banana-based farming system in Bukoba District comprises an integrated mixture of banana, coffee, annual crops, and livestock. Bananas are staple food in

Bukoba District. Due to intensive care by farmers, farm productivity was flourishing in the area until the beginning of the 20^{th} century (INIBAB, 1990). Since 1970s, banana production has been reported to decline. For example Rugalema *et al* (1994) reports a decline of 50% between 1970s and 1990s; while De Weerdt (2003) report a productivity falling from 10t ha^{-1} to about 4t ha^{-1} in the 2000s. However, at Maruku Agricultural Research Institute, the yields of 30t ha^{-1} were documented in the 1990s, which may be considered the maximum potential banana yield for Bukoba (Mbwana, *et al*., 1997).

Major causes of present decline of land productivity in Bukoba District is linked to poor soil fertility management practices, pests and diseases, land shortage and tenure systems as well as poor marketing systems of agricultural products just like other parts of SSA (Yanggen *et al*., 1998). For example, the use of mineral fertilizers in SSA averages to less than 10 kg per cultivated hectare which is less than 10% of average intensity of fertilizer use in developed countries (Ehui and Pender, 2005), and in Bukoba District, the use of inorganic fertilizers is by just 5% (MAFC, 2012). Although poor infrastructure and pricing policies are difficult to quantify, they are also among constraints to farm productivity per unit area in the District.

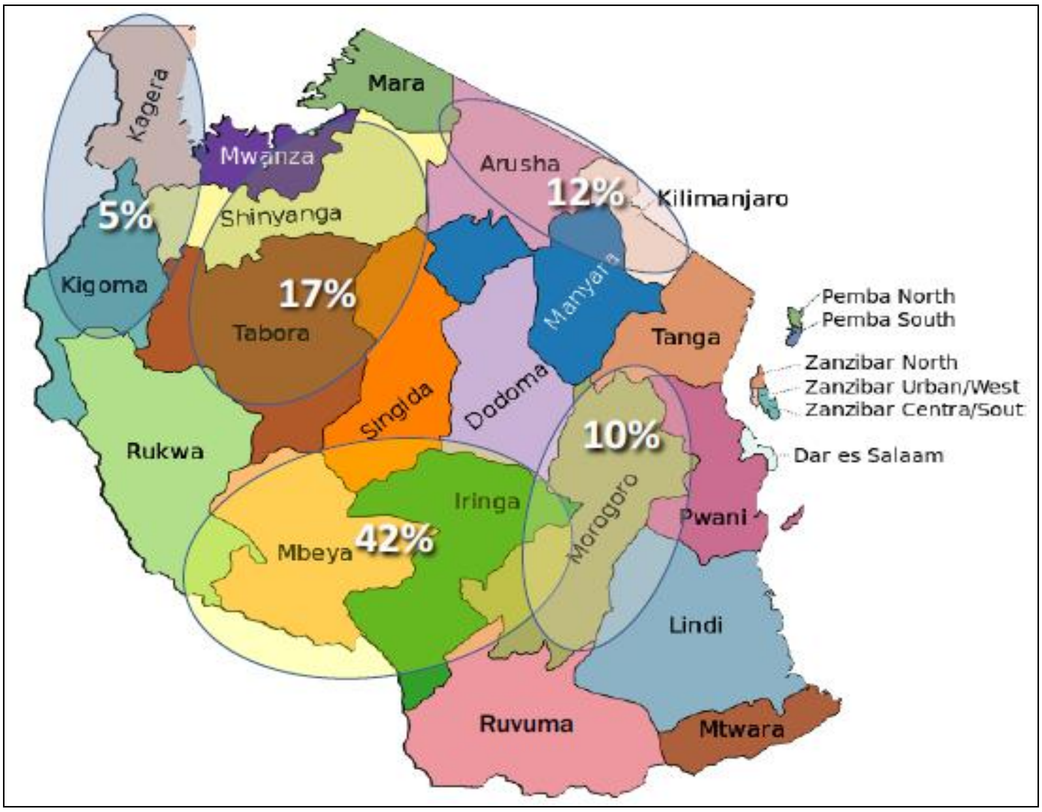


Figure 2: Distribution of Fertilizer Users (% of farmers) across Tanzania (Source-MAFC, 2012)

In fact, fertilizer use in Tanzania is highly concentrated in the Southern Highlands and just a few other regions applying more than half the fertilizer consumed annually (Figure 2). The low incidence and level of fertilizer use in Bukoba District is thus a major contributor to low productivity and thus demonstrates a wide gap between potential yields and observed yields.

According to Rutherford and Phiri (2006), the reduction of crop production and losses pertaining from crop pests and diseases contributes significantly to poor productivity by up to 30%. In fact, past practices of pesticide use cannot be sustained. Concerns are increasing from pesticides use that compromise human health; contaminate soils and water and damage ecosystems; exterminate species; and lead to pesticide resistance, pests' resurgence, and evolution of secondary pests. Evidences show that overuse of pesticides leads to decreased food production through toxicology to flora and fauna (Aktar *et al.*, 2009). Therefore, environmental sound alternatives i.e. integrated pest management, must be developed and adopted. In the 1990s through 200s the government launched two projects namely: Kagera Community Development Program (KCDP) and the Kagera Agricultural and Environmental Management Project (KAEMP). The two projects, however, were addressing declining productivity as emanating from pests and diseases as well as poor planting materials and not land use and tenure systems as regards to the use of grasslands (KCDP, 2000).

Other factors that hinder agricultural productivity comprise low-quality feed (Leng, 1990), and diseases to livestock as well as human diseases such as HIV/AIDS, malaria, and tuberculosis that contribute to farm labour constraints. For example, SSA remains the region most heavily affected by HIV, accounting to 67% of the people infected, and 75% of AIDS death in the world (UNAIDS, 2008).

At the moment, the farming system in Bukoba District is, therefore, challenged with complex interaction of several constraints leading to declining farm productivity (Tibaijuka, 1984; Floor *et al.*, 1990; FSR, 1990; Rugalema *et al.*, 1994; Baijukya, 2004). Although this decline has been a subject to number of investigation (Friedrich, 1968; Mbwana, 1983; Wijnalda, 1996; Baijukya *et al.*, 2005), most past research has focused on the *Kibanja* sub-system and mainly on commodity based research. Nevertheless, to understand this as well as similar farming systems in East African highlands, it is important to analyze the interaction and dynamics of the various elements that constrain the productivity in the context of system analysis approach.

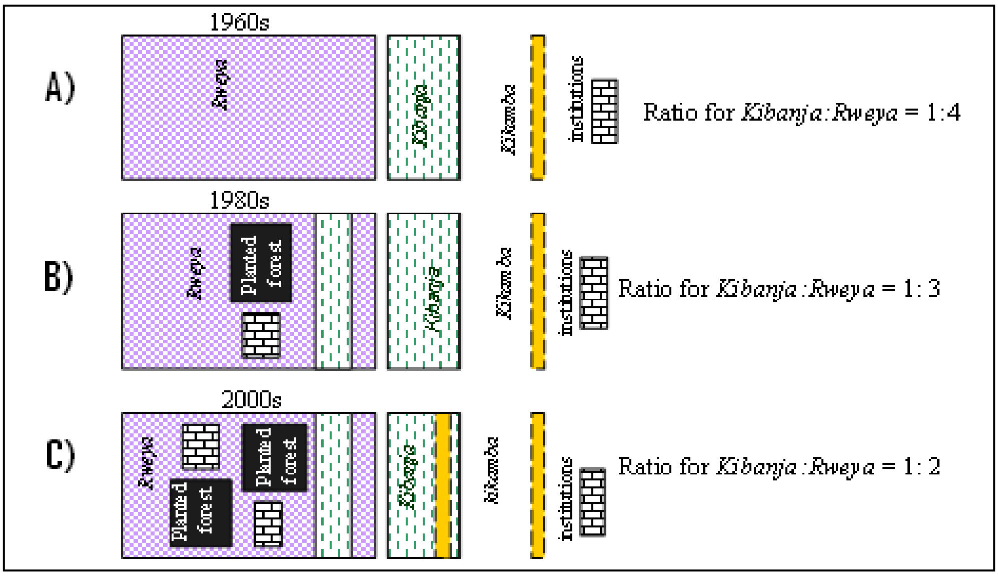


Figure 3: Conceptual model representing the dynamic nature of land use and cover in Bukoba District as perceived over the last 45 years

Key: **A)** In 1960s, the ratio between the *Kibanja* to *Rweya* was estimated at approximately 1:4 considered as adequate; **B)** By 1980s, substantial area of the *Rweya* had been planted by state forests and some encroached by institutions; **C)** In 2000s, a significant area of the *Rweya* was privatized or grabbed by individuals who establish trees plantations, build institutions and *Kibanja* expansion thus reduced the ratio to about 1:2, regarded as inadequate for sustaining the productivity of the *Kibanja* (Source: Baijukya *et al*., 2005).

The *Rweya* is basically used for grazing and therefore source of manure and mulch for crop fields and provide area for shifting cultivation of annual crops especially for landless families. The overall area under *Kibanja* in the District has equally increased due to population growth over the last 50 years at expense of the *Rweya*. Livestock management is gradually changing from free grazing system in the communal land (*Rweya*) to labour and capital intensive system that involve cut and carry under zero grazing system. The contemporary socioeconomic developments in the country and policy changes such as privatisation of parastatal organisations during this period has aggravated land tenure relations thus hinder some households from accessing adequate manure and mulch for their *Kibanja* (KCDP, 2000).

1.4 Objectives of the study

The overall objective of this study was to establish the roles of grasslands in sustainable improvement of land productivity in the banana-based farming system of Bukoba District. Specific objectives for this study were therefore:

i. To identify the factors contributing to decline of grasslands area along with their impact on the productivity of the farming system;
ii. To examine the impact of declining grasslands to various categories of farming households;
iii. To assess the availability in quantity and quality of *Rweya* grasses used as fodder for livestock and mulch grass for home gardens over different seasons in the year;
iv. To determine the quality of fodder for livestock and mulch grass used in home gardens;

v. To explore for sustainability options for farm productivity.

Guiding Research Questions

The following research questions were guiding this systematic inquiry in the two villages where the study was conducted:

i. What are roles of land tenure system of communal lands in farmland productivity and poverty alleviation?
ii. How much is the customary/communally owned grasslands have been affected by the contemporary land tenure arrangements at village level?
iii. What are constraints and opportunities for agriculture development and other non-farm activities in relation to pressure on communal land at local level?
iv. What and how much do grasslands contribute as resources to farm lands and the livestock at household level?

From the cited literature no concise answers to the above research questions and in fact land productivity has not improved to majority of households. This current situation therefore aroused interests to warrant further investigation in this study.

1.5 Outline of the thesis

The motivation for, and major issues addressed in this thesis are summarized in the preceding section of this general introduction in the following diagram:

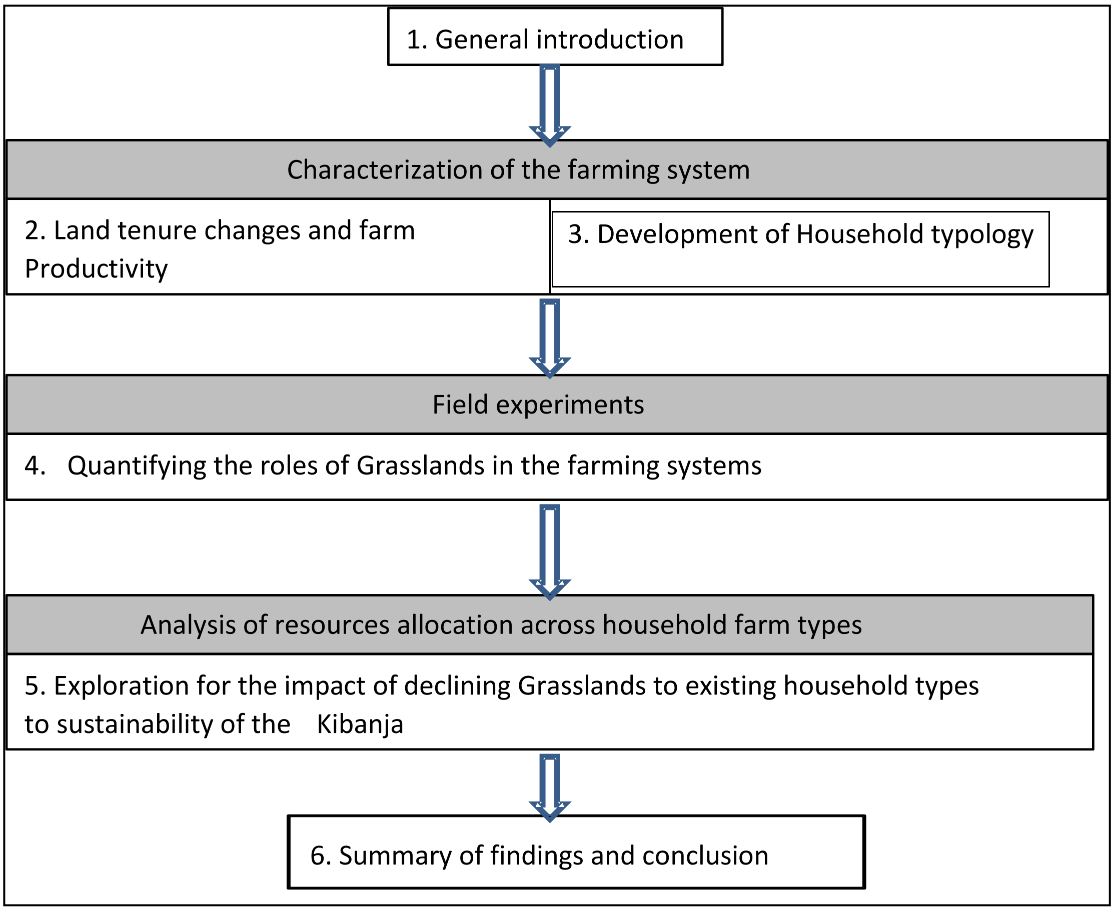


Figure 4: Summary organization of the contents in the thesis

CHAPTER TWO

LITERATURE REVIEW

2.1 Impact of land tenure changes on subsistence agriculture.

Land tenure and livelihoods

Livelihoods in Bukoba District, like other places in Tanzania is directly or indirectly, heavily linked to land as source of fundamental human needs of survival, for habitation, subsistence cropping, or for foreign exchange earnings (Mwijage *et al.*, 2009). However, access to and controls over land resources by farmers have frequently been determined by socio-political structures.

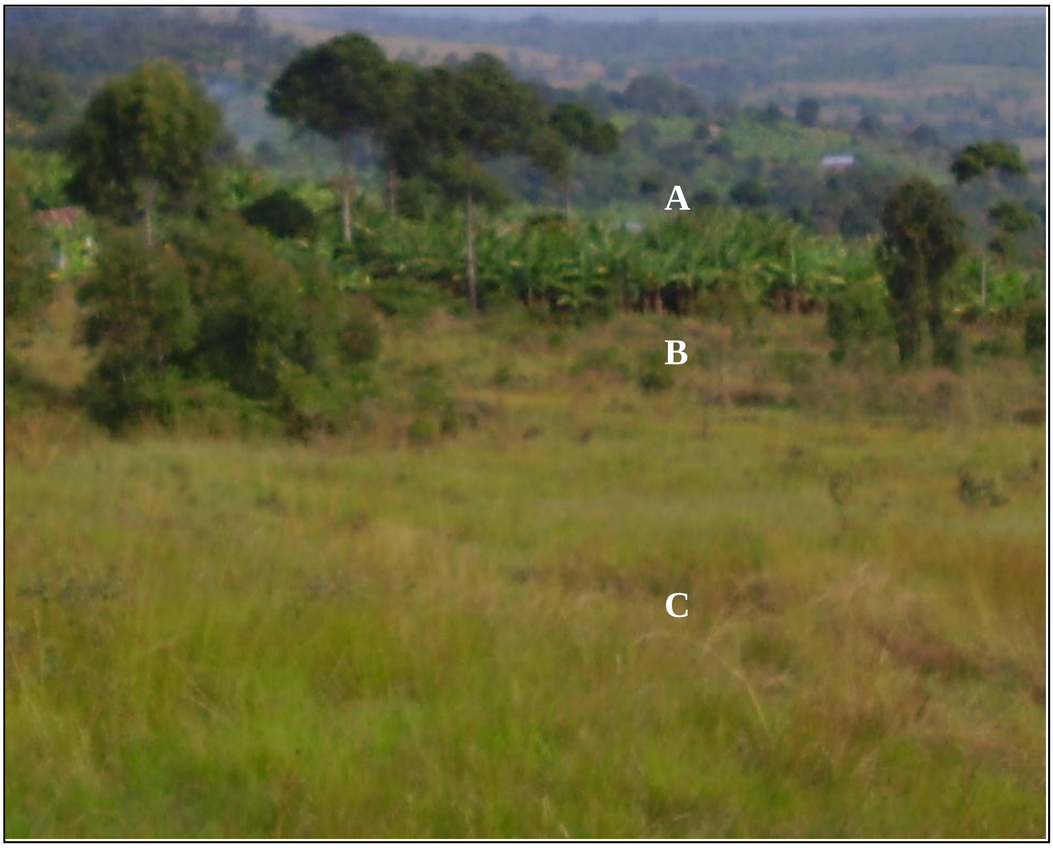


Plate 2: The three main land use types existing in the banana-based farming system in Bukoba District

Key: A: Kibanja; B: Kikamba; C: Rweya

Plate 2 shows the three main land use types predominant in Bukoba District. The study on land-tenure systems analyses the socio-political relationships between man and land and between man and man in respect of land. These relationships have always been fundamental in any economy or society, and they remain particularly so in pre-industrial societies where land usually constitutes the primary form of wealth and source of power, a central factor of production and a major determinant of social structure and prosperity.

Land tenure relationships among members of any society can therefore regulate the security of individuals or group and hence influence social, political and economic stability. They can dictate access to credit and to new technologies, and they may also help to determine the levels of capital formation and investment. They may exert considerable influence over income distribution and consumption patterns, over rural employment and they may also present a primary obstacle to economic development, to new enterprises, and to social change. They may reduce or frustrate economic opportunities; legitimize existing inequalities (Mwijage *et al.*, 2009); limit the power of choice and action of families or individuals; or limit rights of association and prevent the achievement of minimal social and political freedoms (Smith, 2004).

For these reasons, efficient land tenure systems should be of central concern for political leaders, economic planners, and architects of social policy, for they link human with natural resources, and it is only through their examination and analysis that this fundamental relationship may be understood and thereafter planned. However, as observed by (Mwijage *et al.*, 2011), community control and shared management over communal lands in Bukoba District since pre-colonial time to-date has tended to decay, such that the system is now being advanced towards the individualization of property rights. The unprecedented increase in population in the District has also tended to build a closer personal identification with a specific parcel of land particularly the *Rweya*. This has promoted the spread of more intensive methods of land use and as a result, the interdependence of traditional system of land tenure has been found increasingly incompatible with a contemporary market economy.

As for many African countries, weak governmental institutions appear to be a more important cause of pathway to conflicts related to land. At global scale, globalization and centralization of power has grown, and the degree of insecurity has increased. In fact, the world is facing global economic crisis, and, inseparable from this, is a crisis of growing global inequality and rising poverty. These urgent and unprecedented economic and social-political changes pose huge challenges and the signs are there indicating a need for society's cross-sectoral attention to issues pertaining to land tenure systems.

Land tenure and agricultural productivity

In the on-going debate on land rights and tenure change in Africa, an economic model predicting increased agricultural productivity following the establishment of privatized property rights continues to occupy a central position. The assumption that transferable property rights will improve (smallholder) farmers' access to credit and investment often underpins land tenure reform policies although empirical evidence shows mixed results or, suggests that the relation may be different (Deininger and Jin, 2006). A common feature of studies on property rights and land tenure change, however, do focus on tenure arrangements, that is, the set of socio-political arrangements by which access to land is regulated. Understandably, land tenure revolves around issues of governance, as the regulation of the access to land as well as its use defines a tenure system.

Despite unprecedented thinking on transformation of customary land rights by non-customary tenure ideology and legislation provisions, customary tenure systems not only persists, but also is still by far the majority form of land tenure in most countries of Sub-Saharan Africa (Wily, 2000). In fact, land tenure debate often becomes focused on the failure of central government to enforce legislation or to recognize particular local tenure arrangements, or on the need for government to implement tenure change policies. Academic studies (Platteau, 1996), have focused on the social, economic and/or legal pre-conditions for tenure change, thus understanding change in tenure rights as an evolutionary process. Consequently, tenure arrangements tend to become seen as mutually exclusive, and ordered along a linear development path, and often discussed without an appreciation of the land use practices to which these arrangements are linked.

In the context of evolutionary model of land tenure change and agricultural productivity, the World Bank argues that private property is a key incentive for farmers to invest in land and that because of diversity and changing tenure systems, agricultural modernization combined with population pressure makes privatization of land necessary (Toulmin, 2008). The critics of this neo-modernization model argue that the data on which these arguments are based are too weak to support such a claim (Atwood, 1990). On the other hand, Haugerud (1989) shows evidence from Kenya where privatization of land did not lead to significant investment in agriculture because credit funds were most often diverged to other off-farm investments including land speculation. Further evidence from Ghana and Rwanda indicates that privatization of communal land had little effect on productivity of the farming system (Migot-Adholla *et al.,* 1991).

The point of departure is the farming system and its productivity. Hence the focus in this research is on the agricultural systems, which tenure reform policies claim to promote. Building on an analysis of the development of the banana-based farming system in Bukoba District, Tanzania, changes in land use as tied-in with evolving, and yet diverse tenure arrangements are described. Such arrangements cannot simplistically be ordered along an evolutionary development path from open access towards increasingly individualized forms of land tenure, as historically, different tenure arrangements have applied for different land uses. It is these distinct land uses and tenure arrangements combined, which constitute the structure of the farming system and the livelihoods of farming communities. Hence, the case of Bukoba District brings out different perspectives that have wider (policy) relevance; that is tenure arrangements have to be understood in conjunction with the diverse land use practices that they regulate.

Therefore, land tenure and conflicts prevention, mitigation and reconstruction in Tanzania, like in other African countries need to place and interpret the land issues within a specific and particular historical and social context. This would help sort out the land related conflicts without applying or copying generic land reform solutions to intricate land problems.

In the Bukoba District context, farmers face complex constraints regarding decisions in the allocation of scarce land resources for optimum crops and livestock productivity. Often their decisions are influenced by socio-economic factors, which also vary with resource endowment of individual households. As matter of fact, sustainable land use comprises ecological, agro-technical and socio-economic dimensions; but these objectives can be regarded as constraints because they are often given different priorities by different inherent farm types within any farming community. One of key strategy of increasing the resource use efficiency and sustaining them at farm level is to apply an integrated approach of system analysis that integrates socioeconomic and biophysical components of the production system.

In this farming system, therefore, grasslands are important in nutrient cycling and sustainability of the system not only through cattle, acting both as concentrators and transporters, plant nutrients in the form of manure are moved from the grasslands to crop fields, but also farmers enrich soils of crop fields by applying grass mulch obtained from the grasslands, and harvest grasses for other purposes such as thatching. Nevertheless, in this area, accessibility to, and availability of communal land-based resources that are important on productivity of smallholder farms are currently limited to few farmers and is likely to continue like this in future until appropriate programs and policies are put in place. The use of organic inputs such as mulch grass, crop residues, and animal manures are often proposed as alternatives to mineral fertilizers (Giller *et al.,* 2006). However, as observed in the general introduction part, there is rapid decrease of the area under communal land (*Rweya*) in Bukoba that is available for smallholder farmers and which is basic in supplying of fertilizing organic materials to farm lands. This is often worsened by a combination of privatization policies and unrestricted market forces pertaining to land; and by greed and corruption by the rich and powerful individuals leading to changes of tenure systems and use of the land. As the results are limited access rights to common lands by some smallholder farmers in the farming system thus hampering the productivity in their farms (Mwanukuzi, 2009).

In addition to economic policy issues, there is also increasing human population which also has intensified the competition on the use of grassland resources. This is because not only more people tend to use the grasslands but also part of the grasslands is turned into other uses. For example, eucalyptus and pines trees were planted in Bukoba since early 1970s through the recent time for timber and firewood (Mwanukuzi, 2009). Mwijage *et al.* (2011) accounts for an imbalance of nutrient flows within different land use types in the system following disruption of traditional land tenure arrangements in the farming system. Since nutrients moves within the system through manures and mulch grass, an estimate and quantification of organic material resources from the *Rweya* to farmlands is of supreme importance in an effort to explore for system sustainability. Theoretically, at least confinement of cattle should lead to increased quantities of manure becoming available for use on fields around the homestead, which in turn should result in increased productivity. However, there has been no systematic collection of data on manure and mulch availability, utilization and productivity in relation to accessibility to grassland resources, and it is unclear whether there have been any benefits in terms of improved soil fertility and productivity of smallholder farms.

2.2 Variability among farming households (Farm typology)

Smallholder farming systems in Sub-Saharan Africa illustrate a high degree of dynamism and heterogeneity due to complex interactions of socio-economic and biophysical factors (Giller *et al*., 2006; Tittonell *et al.*, 2007). This heterogeneity is related to variability in production objectives and resource endowment status of individual households (Zingore, 2006). The inherent variability often influences responses of farmers to various technologies that aim to improve farm productivity and natural resource management (Lal *et al*., 2001; Emtage and Suh, 2005). This means that many technologies that have been developed on research stations and translated into blanket recommendations are not always appropriate for the entire farming community. The underlying assumptions of researchers and development actors are that farms are similar within the particular farming system, and that less productive farms would follow the target farms, thus adopting new technologies considered superior (Kaihura and Rugangira, 2003). However, farmers with relatively good access to resources can more easily afford the risk associated with changing farm management practices than resource poor farmers (Chambers and

Jiggins, 1987). Thus, efforts to disseminate improved management practices for crop and livestock systems need to take account of this inherent farm diversity.

Bukoba District is one of the most densely populated areas in Tanzania, characterized by the coffee-banana based farming system with ubiquitous land shortage. As in many other parts in Africa, the delineation of this farming system is based on agro-ecological zones distinguished by rainfall, parent material and soils (Lorkeers, 1995). Such broad classification does not take account of the variability among farms in terms of socioeconomic characteristics.

Currently, the productivity of the farming system is declining; a crisis connected to land tenure arrangements that has resulted in an imbalance among basic land use types prevailing in the farming system referred in local parlance as *Kibanja*, *Kikamba*, and *Rweya.* However, understanding the variability in terms of spatial and temporal resource use strategies and opportunities among the farming households is needed to allow design of relevant interventions for improving resource use efficiency at farm scale. Only few studies (e.g. Nkuba, 1997; Maruo, 2002) attempted to classify households in the Bukoba farming system in the past based on farm sizes and farming strategies. Yet, these studies did not take into account of the socioeconomic characteristics, resource endowment base of households and the role of social stratification in access to common property resources. Consequently, the implications of their classification were limited in terms of policy recommendations and technology transfer at farm scale.

2.3 Contribution of grasslands to farm productivity.

Grasslands play major roles in the development and sustenance of sedentary farming systems in most parts of sub-Saharan Africa (Boonman, 1993; Bogale *et al*., 2008). Through cattle, acting both as concentrators and transporters, plant nutrients in the form of manure are moved from the grasslands to crop fields. Farmers also enrich soils of crop fields by applying grass mulch obtained from the grasslands, and harvest grasses for other purposes such as thatching. With increasing human population, competition on the use of grassland resources has intensified; not only more people use the grasslands but also part of the grassland is turned into other uses. For example in Bukoba District, eucalyptus and pines trees were planted since early 1970s for timber and firewood (Mwanukuzi, 2009). Though grasslands are essential in African economies, their contribution to sustain agrarian systems remain poorly understood and are often neglected (Jodha, 1986).

This study therefore is aimed at: i) to understand how local communities use the grasslands and their products; ii) to quantify monthly and total seasonal biomass availability and the relative contribution of different species in the grasslands of Bukoba District; and iii) to quantify the forage value of the available grass species.

2.4 Options for improvement and sustaining the production system

System description

The farming system in Bukoba District is banana-based and is distinct from other forms of crop production in Tanzania (Rald and Rald, 1975; Rugalema *et al*., 1994; Maruo, 2002; Baijukya, 2004). Originally, Bukoba was inhabited by Bantu people who practiced slash and burn shifting cultivation and grew finger millet (*Eleucine coracana* Gaertn.), and yams (*Dioscorea* sp. Molina.), for approximately two millennia before banana came to dominance. In the 16th century the Nilo-Hamitic pastoralists arrived in the Kagera region from the lower Nile Valley and brought cattle with them. The two groups mixed and formed a society, now called the *Haya*, who built up a perennial culture of banana plants by exploiting manure with careful management to enrich the highly weathered soil. Even today replenishment of fertility in banana fields depends mainly on grass materials brought from the surrounding grasslands as mulch, and through cattle manure (Baijukya *et al*., 2005; Mwijage *et al.*, 2011).

The *Haya* farmers classify land use into three main categories: *Kibanja* (*bibanja* – plural) *Kikamba* and *Rweya*. The *Kibanja* is the archetype of the *Haya* rootedness and prosperity where farmers grow bananas inter-planted with Robusta coffee, maize, common beans and root and tuber crops. A Bukoba farmer’s life is anchored in the *Kibanja* where he/she erects a family home. A cluster of several *Kibanja*, each surrounding a homestead, forms a village community, which Milne (1938) describes as ‘an island of fertility in the sea of infertile grassland’. The *Kikamba* consists of land used for cultivation of annual crops – mainly maize, cassava, sweet potatoes yams and occasionally taro (FSR Project, 1990). The *Rweya* is savanna grassland dominated by giant yellow spike thatching grass-*Hyparrhenia rufa* (Nees) Stapf and *Hyparrhenia hirta* (L.) Stapf); Couchgrass (*Eragrostis olivacea* (K. Schum) and *Eragrostis mildbraedii* (Pilg.); Russetgrass (*Loudetia kagerensis* (K. Schum.) Hutch; and yellow thatching grass (*Hyperthelia dissoluta* (Steud.) W.D. Clayton. The grassland is used for communal cattle grazing, as a source of grass for mulching in the *Kibanja*, for thatching of houses and for home carpeting. Shifting cultivation of Bambara nuts (*Vigna subterranean* (L.) Verdc.), cassava and yams is also practiced on small areas of the *Rweya* – a practice known as *Omusiri*. The *Rweya* and *Kibanja* are interdependent and central to the livelihoods and food security of local people. The *Rweya* soils are intrinsically poor, developed on shales and sandstones that are well drained, very deep to moderately deep sandy clays to clay loams.

Like most other areas of SSA, smallholder farmers in Bukoba District, faces complex constraints regarding decisions in the allocation of scarce land resources for optimum crops and livestock productivity. Often farmers' decisions are influenced by socio-economic factors, which also vary with resource endowment of individual households. In addition, land shortage, degradation and ecological imbalance among the dominant land use types. As matter of fact, sustainable land use comprises ecological, agro-technical and socio-economic dimensions; but these objectives can be regarded as constraints because are often given different priorities by diverse farm types. One of key strategy of increasing the resource use efficiency and sustaining them at farm level is to apply an integrated approach to the management of soil nutrients along with other complimentary measures (Tittonel *et al.,* 2007).

The existing variability among farming households in Bukoba farming system is linked to the use of conventional farm inputs. However, research done in Thailand suggests that there is a significant scope to improve productivity through efficient use of available resources such as organic and inorganic fertilizers, good planting materials, machinery, livestock, labour, and land (Cho and Zoebisch, 2003). For example, incorporation of herbaceous legumes that fix atmospheric nitrogen in the degraded soils is one of recommended solution to soil fertility problem in Africa (Giller *et al*., 2009). In Bukoba farming system, the use of organic materials in the form of mulch and manure has been widely used in soil fertility management for long time past and to-date, remains the only affordable means to majority of smallholder farmers. Certainly, organic materials alone are not enough and are unlikely to guarantee sustainable soil productivity particularly in the highly depleted soils. Hence, an integrated approach that helps to design for efficient use of available resources is recommended (Tittonnel *et al.*, 2005; Giller et al., 2006;). To accomplish this, and perhaps to reverse the deteriorating situation, appropriate policies are needed because farmers' dependence on farm inputs based on organic resources alone to maintain or to improve the productivity of farms is no longer assured. Therefore, the current study was designed in order to determine future opportunities available for keeping the productive farming system.

In order to address the sustainability objective, a Multiple Goal Linear Programming (MGLP) model was developed to explore options of different land use scenarios. The aim was to address these issues through meeting farmers' objectives of maintaining the productivity of the *Kibanja* while considering environmental objectives of positive N and K-balances for the *Kibanja* that addresses sustainability scenario.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

Bukoba is a District in Kagera region, north-western Tanzania, located on the western shore of Lake Victoria (1^{o}-1^{o}30'S and31^{o}-32^{o}E) within altitudes ranging from 1150 to 1600 m.a.s.l, covering about 786,000 ha. The District is bordering Uganda on the northern side, Lake Victoria on the east, Muleba District on the south, and Karagwe and Misenyi District on the west as indicated in Figure 1. For purpose of effective planning for peoples' livelihoods in terms of agriculture and natural resources management, the District is broadly divided into two main agro-ecological zones: the high rainfall zone and the low rainfall zone, following the criteria of rainfall, soils, population density and agriculture. The District has total population of 290,000 and around 66,000 households (NBS, 2013). Area coverage for dominant land use types in Bukoba District consist of the following: *Kibanja* covers approximately 28%, *Rweya* 25%, *Kikamba* 7%, and others - planted and natural forests, institutions, water bodies, swamps 40% (Baijukya *et al.*, 2005).

Figure 5: Map indicating the location of Bukoba District and boundering Districts

Rainfall distribution follows a bimodal pattern and annual rainfall ranges from 900 to 1500 mm in the low rainfall zone (LRZ) and 1500 to 2200 mm in the high rainfall zone (HRZ). Soils are classified as Alumihumic Ferrasols, inherently poor in fertility, developed from sandstones and shale materials that are highly leached (Touber and Kanani, 1994). Soil fertility and productivity of *Kibanja* depends on large application of organic inputs mainly from the grassland (*Rweya*) as mulch and manure.

In the study area, there is large degree of soil heterogeneity, which is the consequence of the inherent soil-landscape variability, high soil nutrients leaching and the effect of past and current land management (Tittonel *et al.*, 2010). The status and variability of soil fertility within smallholder farms are therefore likely to vary between households of different social status, cattle owners vs. non-cattle owners, or between those pursuing different long-term objectives like market orientation or subsistence farming. The district whose total area is 1,653.91 km^2, is a densely populated highland (176 persons km^{-2} (NBS, 2013). The smallholder farms range from cash-oriented coffee growers through semi-commercial cereal and roots and tubers-based systems. In general, continuous cropping with few or no nutrient inputs coupled with removal of crop residues from the fields has led to a general poor fertility status of the soils (Shepherd *et al.,* 1997).

3.2 Communal Land Tenure in Relation to Productivity and Poverty Alleviation (objective 1)

Questionnaires were designed to collect socioeconomic information through interviews to farmers within study villages. Historical data on changing land tenureship and socioeconomic information was composed from archives and through household interviews, focus group discussions, and from individual interviews as well as by physical observations during transect walking in the study area.

The survey data were collected from two villages namely Butahyaibega (1^o7'S and 31^o48'E) and Butulage (1^o29'S and 31^o 30'E) in Bukoba District. These villages are located in the High Rainfall Zone (HRZ) and Low Rainfall Zone (LRZ)), respectively of the farming system. Oral historical data on changing land tenureship were obtained through focus group discussions and key informants interviews at various stages. The discussion started with 20 elderly participants per village (in equal proportion of men and women) forming a focused groups in order to solicit their perceptions as regard to access and control of available grasslands in their village. Selected farmers were those considered knowledgeable on use of grasslands by the villagers at the meetings after we had explained the objectives of the study. This was followed by household surveys in each village, i.e. Butahyaibega and Butulage. Interviewed farmers were randomly selected from the village register, initially by stratified sampling (wealth groups) followed by simple random sampling for each strata of farmers. The generated information was collocated against time lines of locally significant events including famine and other significant political events. Review of published and archival information provided policy information, historical statistics, and dates against which to compare farms and community scale trends in land management and productivity (Reining, 1967; Rald and Rald, 1975).

Data analysis

The research was explorative and thus the data were analyzed using explorative techniques for survey and interview information. The analysis began when data collection started using various data collection tools including written notes or audio-recordings of what were observed during each session of data collection. Some quantitative information was analyzed using SPSS software for descriptive statistics.

3.3 Study on farming typology (objective 2)

Participatory rural appraisal

Administratively, the District comprises 94 villages in 29 wards. Based on the authors' previous knowledge of the farming system, one village was purposely selected from each of the two rainfall zones: Butulage (724 households) in the LRZ and Butayaibega (890 households) in the HRZ, to represent the farming system in the District.

In each village, a meeting was initially held with village members to introduce the objectives of the study. Participatory rural appraisal (PRA) techniques were applied in the course of the discussions with community members and in identifying common property resources (Chambers, 1994). The introductory meetings were attended by 225 and 193 members representing 25% of households in Butulage and 27% in Butayaibega villages respectively. During these meetings the participants were split into three groups defined by gender and age: namely elderly women, and elderly men (aged of 40 and above years), and youths (male and female under 40 years). These groups discussed (independently) issues related to available natural resources, access and control of common resources as well as land productivity in their farms. This process allowed the researchers to capture how different social groups perceived common resources.

At the end of the meetings, each group elected three members who were considered to be well informed about the socio-economic environment of the area. These elected farmers joined the village government leaders to form focus groups of 12 and 17 key informants in HRZ and LRZ respectively, who were involved in self-wealth ranking exercise of the households in the respective villages.

With the facilitation of a multi-disciplinary research team and local extension workers, the focus groups were asked to identify criteria to distinguish wealth classes in their village (Grandin, 1988; Sharrock *et al.*, 1993). This resulted in the identification of four wealth classes in each village. These classes were named according to their distinguishing resources as wealthy (RG1), average (RG2), poor (RG3) and very poor (RG4) resource groups. The wealth-ranking criteria were based on livestock ownership, the assets owned (such as the quality of the house, motorcycle, bicycle, television and a radio); *Kibanja* area (for Butulage) and tree planting practices (which was mentioned in Butayaibega village as a land holding strategy). Other socio-economic criteria used in wealth-ranking included ability to hire labour or sell labour and access and use of farm yard (kraal) manure and mulch in fertility management of the *Kibanja*.

Using a village register, the focus group then allocated all households into one of the four wealth groups (RG1 to RG4) (Guinand, 1996). In doing so, we aimed to capture community perceptions regarding the existing household diversity and to ensure that the entire range of the community was adequately represented during the subsequent stage of system characterization.

System Survey

A stratified sampling technique was used to select households from all wealth categories in each village for a rapid system survey. A final sample comprising 74 households (out of 890) from Butayaibega (HRZ) and 77 households (out of 724) from Butulage (LRZ) was interviewed. From each wealth group about 10% of the households were randomly selected within a group for further detailed enquiry and monitoring. A standardized questionnaire was used to obtain qualitative and quantitative information from these households related to land holding, labour relations and availability, type and number of livestock owned, the farm inputs used, production activities and orientation (i.e. whether commercial or subsistence), farm income, general overview of food security and farm assets. Table 1 lists the variables identified by farmers from the focus groups during wealth ranking exercise and variables identified by the researchers, i.e. .related to socio- economic and the use of common property resources.

During the rapid survey, interviews were held with household heads (male or female). In instances where the male headed household was absent, the spouse was interviewed. The respondents consulted other members of the households when they were uncertain how to answer questions.

The household (in this case defined as a domestic unit that consists of family members who live together along with non-relatives such as servants, occupying spaces and possessions), was used as basic unit of analysis. Table 1 presents a list of variables that quantify the resource groups. However, household assets not related directly to agricultural production (i.e. house quality, ownership of bicycle, motorcycle, television and radio) were excluded from the analysis at this stage.

Data Analysis

Data were subjected for analysis using multivariate analysis techniques using SPSS for descriptive statistics and Principal Components Analysis (PCA) using CANOCO for Windows version 4.5 (Braak, 1995; Braak and Smilauer, 2002). The first PCA was based on researchers' variables and the second on farmers' variables. The original values of predictor variables were transformed as *Y=log* (original variable values) and also were standardized before the analysis so as to eliminate the effect of differences of scales of measurements. Results were represented graphically as a distance biplot (Braak, 1995).

Table 1: Variables derived by key informants and the variables identified by researchers for farm grouping in Bukoba District, northwest Tanzania

Variable	Farmer-variables		Researchers' variables	
	HRZ	LRZ	HRZ	LRZ
Livestock ownership				
Indiginous cattle (*Icattle*)	√	√		
Improved dairy cattle (*Dairy*)	√	√		
Goats (*GTS*)	√	√		
Chicken (*CKN*)	√	√		
Pigs	√	√		
Household assets				
House quality (*HSE*)	√	√		
Owning a motorcycle (*Motcy*)	√	√		
Owning a bicycle (*Bicyl*)	√	√		
Owning a television (*TV*)	√			
Owning a radio (*RAD*)	√	√		
Land holding				
Kibanja area (ha) (*Kib*)		√	√	
Kikamba area (ha) (*Kik*)			√	√
Rweya area owned (ha) (*Rwey*)			√	√
Trees planted (ha) (*Tree*)	√			√
Socioeconomic attributes				
Labour hiring (*Lhire*)	√	√		
Labour selling (*Lsel*)	√	√		
Labour exchanged (*Lexh*)	√	√		
Family farm labour (*HHL*)			√	√
Farm income (*F_inc*)			√	√
Off-farm income (*Off_inc*)			√	√
Use of *Rweya* resources				
Bedding grass (*Bedding*)			√	√
Mulch (tons/ha year^{-1}) (*mulch*)		√	√	
Fodder cutting (*Fodder*)			√	√
Access to grazing land (*grazing*)			√	√
Dependence on *omusiri (msirwe)*			√	√
Carpet grass (tons/year) (*carpet*)			√	√
Manure collection (kg/month) (*MNR*)	√			√
Total	15	14	12	12

PD = Person-day, equivalent to labour provided by one adult person with age between 18-59 years working for 8 hours a day. The equivalence for different age groups in years is calculated as: ≥ 60 (0.8); 14 - 17 (0.8); 5 - 13 (0.5), 1 - 4 (0.25).

Detailed household characterization

Based on pattern of the variables on PCA ordination biplot, and the relative location of households, 19 households were identified for detailed characterization as case studies. These households were selected to represent the observed variation indicated by the PCAs analysis for each farm as a system (Herrero *et al*., 2007). The data collected in the detailed study included: farm location; household income and expenditure and market information; household economic information; crop and livestock management; land holding and farm size; land management (including all farm inputs and outputs); biophysical information, labour relations, and food calendar. Triangulation approaches were used by visiting the households repeatedly to validate the information obtained from the rapid system characterisation. Farmers' activities were monitored over a period of one year.

Annual income from the farm was calculated from total sales of crop and livestock products. The costs of production incurred in the production process were also estimated. Off-farm income comprised all non-farm related income including remittances, waged labour, trading, fishing, hand craft and tailoring. Income from local brewing was considered farm income if over 50% of the used bananas for brewing were collected from the farm; otherwise if more than 50% were purchased for brewing it was considered an off-farm activity. Family labour allocated to farm activities were calculated in person-days (PD) from the number of family members working full time or part time and corrected for age and sex (Herero *et al.,* 2005). A full time person-day was defined as adult person of 18-59 years age working 8 hours a day. Total labour input in the farm was calculated for one year. Qualitative variables were assigned rank numbers for the analysis. For instance, ‘dwelling’ in four different kinds of houses (mud with grass roof, brick walls with grass roofs, burnt bricks with iron roofs, burnt and cemented bricks with iron roofs) were ranked from 1 to 4.

All farm inputs and outputs were monitored throughout the data collection period. Based on the data on organic inputs into the farm and the harvested products (outputs in DM) and on the mineral mass fractions of nutrients in these inputs and outputs from previous studies (Herero *et al.*, 2005; Kop, 1995), nutrient balances were calculated. The calculations were limited to N, P, and K for the *Kibanja* home garden and *Kikamba* plots by subtracting total outputs in the form of harvested products such as bananas, coffee, beans, root and tuber crops and fruits used for household consumption and sales. Nutrients inputs and outputs by natural processes such as N_2-fixation, losses due to erosion, and leaching were not considered in these calculations due to lack of data. In this farming system, however, farmers do not apply mineral fertilizers in their farms. Animal (farm yard / kraal) manure and grasses in the form of mulch are the main inputs in the *Kibanja* with primary objectives of soil fertilization, moisture conservation and weed suppression.

The data on household food security included all family monthly consumption of food from own farm and purchases from the market. These were all used to compute family food intake in terms of energy and protein. Requirements of nutrient supply were calculated on the basis of World Health Organization standards for energy and protein requirement with minimum thresholds set for sub-Saharan Africa; based on family size and consumption (Herrero *et al.*, 2007). Data handling and analysis was performed using an Integrated Modeling Platform for Animal-Crop sysTems (IMPACT) tool (Herero *et al.,* 2005).

3.4 Quantifying the contribution of grasslands to productivity of smallholder farms (Objective 3 and 4)

Assessment of local knowledge on Rweya use and management

Local knowledge on the availability and uses of *Rweya* grasses was assessed using participatory rural appraisal tools with a group of 18 and 21 elderly male farmers (with age of above 55 years) in Butahyaibega and Butulage villages, respectively. Farmers that were involved to provide information under this objective were identified by the community herdsman by involving farmers whom he thought were experienced in making decisions in the selection of cattle grazing areas as criteria for appropriateness for farmers to participate in the study. Seven and ten of the participating farmers in respective villages were cattle keepers. A questionnaire was used to gather the information on land and livestock ownership, manure production and grasses collected from the *Rweya* for different uses. Transect walking were conducted in the surrounding *Rweya* with participating group of farmers to ascertain which grass species are used and for what purpose. During the assessment, farmers were asked to list all grass species collected from the *Rweya*, their uses, and availability at different times of the year and described how the *Rweya* is managed.

***Rweya* Productivity measurements**

An experiment was established to measure productivity of the *Rweya* in a representative area of the *Rweya* considered by local experts as representative for grasslands that had not been cultivated for over 10 years. Experiments were conducted at two villages namely Nkenge (S 01.2438; E 31.6105; 1137m.s.l) and Maruku (S 01.41668; E 31.78084; 1342m.s.l) both at the slope of approximately 2%. The mean monthly temperatures for 30 years record 16^{o}C (minimum) and 26^{o}C (maximum) for Maruku station. Rainfall at the experimental sites follows a bimodal pattern with the annual mean (for 40 years) of 2100 mm and 1400 mm for Maruku and Nkenge respectively having peaks in April and November. Composite soil samples were collected at depths of 0-20 cm, and 50-75 cm for analysis of physical and chemical parameters. The samples were air dried, ground to pass a 2 mm sieve, and analyzed for texture, pH, organic carbon, exchangeable bases and base saturation following standard procedures (Page *et al*., 1982).

Plate 3: An experimental area at Nkenge village fenced soon after burning in the *Rweya* where measurements was done

Plate 4: Identification of grass species personally at experimental area at Maruku in the *Rweya* where sampling was done

To determine the available biomass of different grasses over a 12 month period, the identified experimental sites were burned during the dry season to mimic local management of the *Rweya*. The burned areas at both locations were subdivided in three blocks, each having 30 m x 10 m, and were fenced to keep away from disturbances from grazing and harvesting. The first measurement was done one month after burning and subsequently sampling was done at monthly intervals so as to last for one year cycle. A metallic quadrat (1 m x 1 m) was randomly located for sampling. Before cutting, all aboveground biomass material within each quadrat was carefully identified by species according to Clayton (1970) and (Clayton *et al*., 1974). Common names for collected species were identified based on Vesey-Fitzgerald (1973). At each sampling time, five quadrats were taken from each plot.

For each successive sampling, the cuts were taken not closer than one meter from the sampling point of the previous month. Harvested plots were marked by date of harvest so that biomass of re-growth could be estimated two months later. This re-growth is normally grazed and can be considered as biomass available for livestock, whereas the biomass developing over time after burning is harvested for other uses. The sorted samples were oven dried at 70^0C for at least 72 hours to constant weight. Average biomass available (kg DM ha^{-1}) each month was calculated by summing the biomass of all species per quadrat, and subsequently averaged over all quadrats per block and over the three blocks (Singh *et al.,* 1975). Final biomass production was the total production (live and dead) at the last sampling month.

Analysis of Nutritive Value of Rweya Grasses

A composite sample of fifteen dry samples of every grass species was made from three consecutive months (July - September; October – December; Jan –March; and April - June); comprising mixtures of green herbage and standing hay. These samples were analyzed in the department of Animal science and Production at Sokoine University of Agriculture (SUA) for quality parameters after were grinded to pass a 1 mm sieve using a Christy Hunt Engineering Ltd Type 8 mill (England). The samples were analyzed for crude protein (CP) and ash using standard procedures (AOAC, 1990). Crude fibre (CF) and acid detergent fibre (ADF) were analysed using ANKOM technology ($ANKOM^{200}$ Fiber Analyzer, ANKOM Technology Corporation, Fairport, NY). *In vitro* dry matter digestibility (IVDMD) was determined using rumen liquor collected from fistulated dry cows before morning feeding according to the procedure of Tilley and Terry (1963). The liquor was filtered through four layers of surgical gauze into conical flasks submerged in a stationary water baths for incubation at 37^oC (Grant Instruments (Cambridge), England).

Data analysis

Descriptive statistics were used to analyse the information gathered from surveys and discussions with farmers. Experimental data were subjected to analysis of variance (ANOVA) using GenStat Release 10.2 (2007). The effect of sampling periods (seasons) on different species and dry matter, and nutritional quality parameters was determined by regression model for grass yield parameters:

$y = \beta_o + \beta_1 x + \varepsilon$ …………………………………………………………………. (1)

Where: $\boldsymbol{\beta_o + \beta_1 x}$ was mean value of the dependent variable (*y* - Yield) when the value of the independent variable is $\boldsymbol{x}$ (sampling time) and $\boldsymbol{\varepsilon}$ is the error term that describes the effects on yield of all factors other than the value of the independent variable i.e. time.

Biomass production from monthly increase for each species during the growing period was estimated according to the procedure described by Milner and Hughes (1968) using the following relationship:

$DM\ (g/m^2) = \sum_1^n (B_n - B_{n-1})$ ………………………………………………..(2)

Where B_n = biomass for n^{th} sampling month at (time t_n)

B_{n-1} = biomass of a previous sampling month (time t_{n-1})

3.5 Exploring options for system sustainability (Objective 5)

The boundary of the modeled system represent a typical set-up of a smallholder farm in the banana–based farming system in Bukoba District where farmers operates within three interrelated sub-systems or land use types (i.e. *Kibanja*, *Kikamba*, and *Rweya*). The model is illustrated in Figure 6 demonstrating the scenery of resource flows between sub-system components.

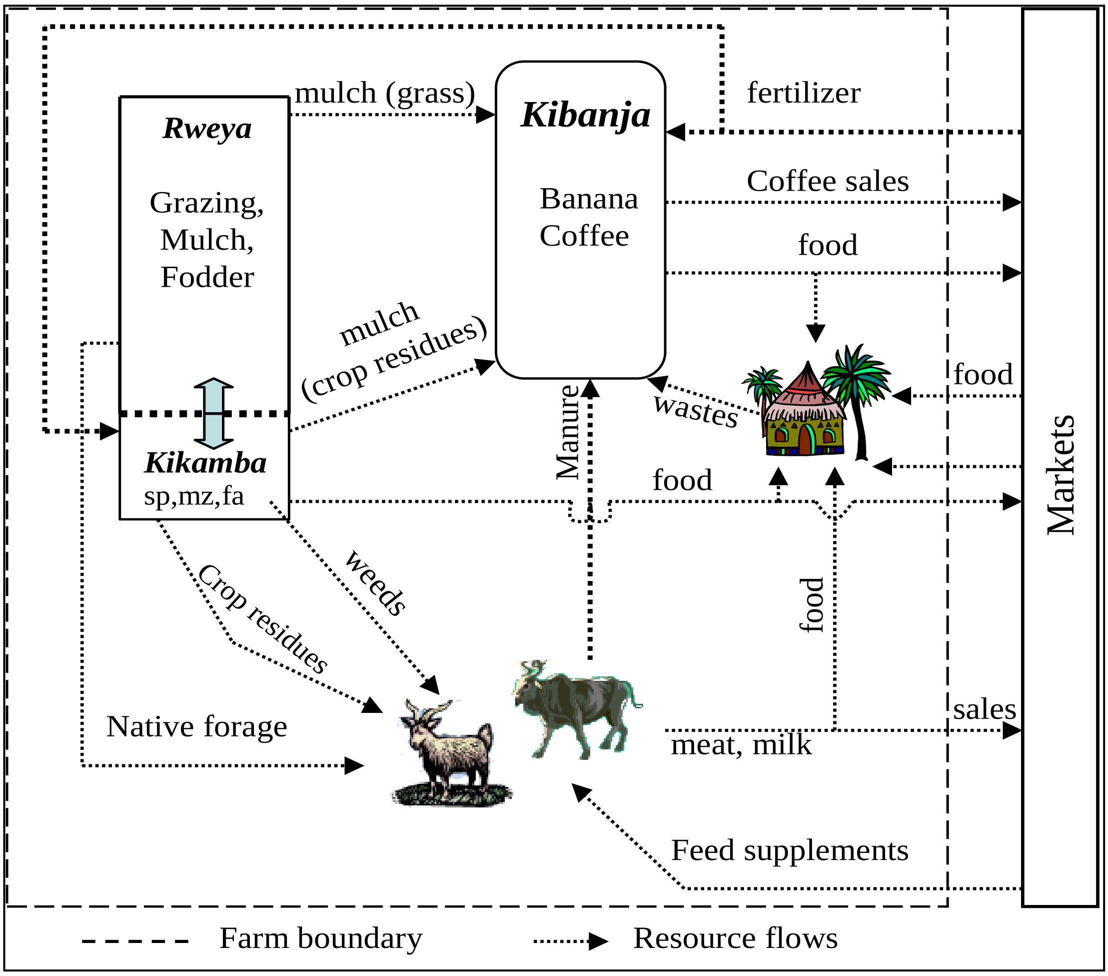


Figure 6: Conceptual model representing resource flows (N and K) between the sub-system components of the smallholder farmer in Bukoba District demonstrating the boundary of the system involved in the model, and main crops grown in each sub-system. *Key:* Sp= sweet potato; mz=maize; fa= fallow

Production activities and input-output combinations

The *Kibanja* activities

The *Kibanja* sub-system is dominated by perennial crops mainly the East African highland bananas, grown as staple food crop in mixture with coffee as major cash crop. Two perennial crops (banana and coffee) were considered to define the *Kibanja* activities in the model. Based on literature we know, the current yield level of bananas ranges from 600 – 1000 kg DM $ha^{-1}yr^{-1}$ (Mwijage *et al*., 2009), depending on farmers' management. However, given different levels of nitrogen and potassium in the soil, the estimated banana potential yield was calculated and set between 1000 – 8000 kg DM ha^{-1} for the second growth cycle at dry matter content of 25% of field weight (Nyombi *et al*., 2009). Yields of clean dry coffee were estimated at 300 – 2000 kg ha^{-1} $year^{-1}$ depending on soil fertility and farmers' management. We considered nitrogen (N) and potassium (K) as variables because these are the most limiting nutrients in the *Kibanja.* Although these nutrients work in synergy with Phosphorus (P), the latter is generally not a constraint as it is available in adequate amount in Bukoba soils (Janssen, 1993; Deugd 1994).

Nitrogen and Potassium requirements as inputs for alternative production levels of banana and coffee were calculated based on target yield oriented approach in view of concentrations of nutrients in the products (Ittersum and Rabinge, 1997), and farm surveys for actual yields. The indigenous soil supply of nutrients i.e. the potential soil supply for nitrogen (SN), and potassium (SK) in kg ha^{-1} was estimated based on chemical properties of *Kibanja* soils (Table 2), and using the Quantitative Evaluation of Fertility of Tropical Soils (QUEFTS) model (Janssen *et al*., 1990; Tittonell, 2008).

Table 2: Average chemical and physical characteristics of top soil (0-30cm) from *Kibanja, Kikamba*, and *Rweya* soils in the HRZ of Bukoba District

Characteristics		land use type		
		Kibanja (n=24)	*Kikamba (n=24)*	*Rweya (n=18)*
Textural class	Sand (%)	67	59	70
	Silt (%)	7	14	8
	Clay (%)	19	20	23
Chemical characteristics	pH (H_20)	5.7	5.5	5.2
	OC (g kg^{-1})	26	22	26
	Total N (g kg^{-1})	2.2	1.7	1.3
	P-Total (g kg^{-1})	2.3	2	1
	P-Bray (g kg^{-1})	12.3	2.1	1.3
	Exch. Ca (cmol kg^{-1})	4.9	1.3	0.9
	Exch. K (cmol kg^{-1})	0.4	0.2	0.1

(Source: Touber and Kanani, 1994)

Estimation of the indigenous available levels for N and K were therefore calculated based on the relationships:

$SN = fN * 50 * SON$ …………………………………………………...………….. (3)

$SK = 1018.6 * K_{saturation} + 13.8$ ………..…………………………..…...………….. (4)

where f = correction factor related to pH (H_20);

$K_{saturation} = 0.0768 – 0.0018 * SOC$. ……………………………...……..……… (5)

Soil organic carbon (SOC) and soil organic nitrogen (SON) are expressed in g kg^{-1}, whereas exchangeable K is expressed in cmol kg^{-1}. The correction factor for N was calculated from the relationship:

$fN = 0.25 (pH - 3)$ ……………………………………….……………..……….. (6)

Nutrient recovery fraction for organic materials (i.e. mulch and manure) in the *Kibanja* was assumed at 75%. Mulch and manure in the *Kibanja* has advantage of adding soil nutrients, moisture conservation, weed suppression, and improvement of chemical and physical properties of soils. The relationship between the amount of applied material inputs at the target yield ($F_{applied}$), the nutrient uptake at target yield (NU_{target}), indigenous soil nutrient supply ($N_{indigenous}$), and Nutrient Recovery Fraction (NRF) was expressed in the relationships:

$$NU_{target} = N_{indigenous} + \left(NRF * F_{applied}\right) \quad (7)$$

$$F_{applied} = \frac{\left(NU_{target} - N_{indigenous}\right)}{NRF} \quad (8)$$

where NU_{target} = total plant nutrients uptake by the crop at harvest of target yield (kg ha^{-1}, based on bunch weight for banana and clean hulled coffee), $N_{indigenous}$= the indigenous supply of nutrients (kg ha^{-1}), NRF = nutrient recovery fraction of applied soil amendment materials and F = amount of fertilization materials applied (kg ha^{-1}). The indigenous nutrient supply, calculated according to equations 3 – 6, provided 74 kg N ha^{-1}, and 35 kg K ha^{-1}. The uptakes of nitrogen by the plant were assumed to be 5% of the organic nitrogen in the soil (Azam, *et al.,* 1985), and for Potassium, the uptake was assumed at 10% of the soil supply (Schenk and Barber, 1980). Yield of bananas were calculated based on planting density of 1100 mats ha^{-1} in pure stand, while in mixture with coffee was estimated at 270 trees of coffee and 570 mats of bananas ha^{-1} (Simmonds, 1966; Rald and Rald, 1975). Nutrients supplied by the added materials as inputs and those taken up by crops through harvestable products of bananas and coffee (outputs) were calculated based on mass fractions in the products (Table 3). A *Kibanja* was assumed to contain 60% bananas and 40% coffee with two thirds of the banana planted close to homestead, while one third of banana are planted in a mixture with coffee farthest from the homestead. Having this crop architecture, two land use activity was defined for the *Kibanja* namely: banana in pure stand, and the mixture of banana and coffee, each at three technology levels defined by input levels (i.e. low, medium, and high).

Table 3: Nutrient concentration in organic inputs and outputs in the *Kibanja* (g kg^{-1} DM)

	N	K	Source
Inputs materials			
Mulch (native *Rweya* grass)	5	8	Research data, 2011
Mulch (forage legumes)	32	7	Baijukya, 2004
Manure (free grazing)	15	12	Kop, 1995
Manure (zero grazing)	20	17	Kop, 1995
Maize Stover	6	7	Palm *et al*., 1997
Outputs			
Banana harvests	66	265	Nyombi *et al*., 2009
Coffee harvests	170	33	Winston *et al*., 1992

Fertilizer inputs

Inorganic fertilizers are potential input for the *Kibanja* to supply the required nutrients for production of banana and coffee. However, parts of nutrients are lost through natural processes such as leaching, erosion, volatilization, and denitrification. Nutrient losses from fertilizers in this farming system through these processes were estimated at 43% for N, and 7% for K (Eijk, 1995).

Cropping seasons

The cropping calendar in Bukoba District is based on two broad periods referred to as long rain and short rain, respectively, each being divided into two minor seasons as illustrated in figure 7, for which the model was based. Main farm operations during the cropping seasons include: harvesting for maize, sweet potatoes, coffee, and banana; land preparation for sweet potatoes, maize; manure application; mulching the *Kibanja*, detrashing and desuckering bananas as well as planting maize and sweet potatoes.

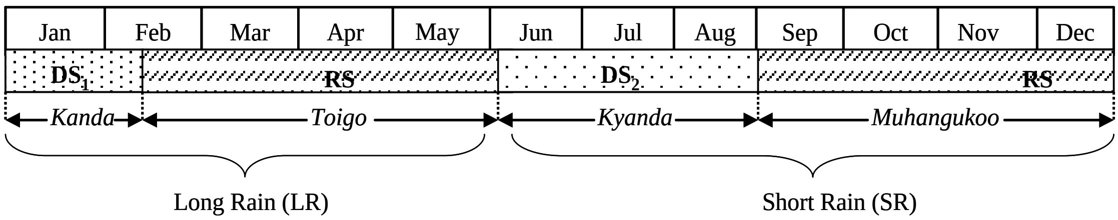


Figure 7: The four seasons (*kanda, toigo, kyanda,* and *muhanguko*) in the banana-based farming system in Bukoba District indicating the two main periods (long rain and short rain) on which the farm model was defined i.e. long and short rain periods. Key: DS: Dry spell; RS: Rain season

Description of *Kikamba* activities (annual crops)

The *Kikamba* refers to reserved land for cultivation of annual crops in various rotations. Two food crops: Sweet potatoes (*Ipomea batatas*) and maize (*Zea mays*); six herbaceous legumes *Tephrosia candida* (Ltc), *Clotaralia grahamiana* (Lcg), *Mucuna pruriens* (Lm), *Macrotyloma axillare* (Lma), *Macroptilium atropurpureum* (Lmat), and *Desmodium intortum* (Ld) were involved in defining the *Kikamba* activities. The weeds in the rotations were considered as a crop because could be used as input to the *Kikamba* during land preparation for sweet potatoes cultivation. The outputs from the *Kikamba* include harvests of food crops (maize grain and sweet potato tubers). Sweet potato vines, Lm, Lma, Lmat, Ld and maize stover can be used as fodder. Lm can also be used as mulch in the *Kibanja* and incorporated in the *Kikamba* plus Ltc, Lcg, Lm and weeds can be incorporated into the *Kikamba* soils during sweet potato cultivation, while maize stover can be mulched in the *Kibanja.* Different options for use of *Kikamba* residues are summarized in the Table 4 below:

Table 4: Summary of different uses of *Kikamba* outputs in relation to fertility management considered in the model (herbaceous legumes and crop residues)

Use of outputs	*Ltc*	*Lcg*	*Lm*	*Lma*	*Lmat*	*Ld*	weeds	Mstover	sp
Incorporation into *Kikamba*	√	√	√				√		
Mulched in the *Kibanja*	√	√	√					√	
Used as fodder to livestock			√	√	√	√		√	√

Conditions on which *Kikamba* rotations were fixed:

No maize grown during the long rain season;

No *Tephrosia candida* (Ltc) or *C. grahamiana* (Lcg) during short rain season and can only be used as a green manure;

No fertilized maize in combination with legume(s);

No sweet potatoes in combination with legume(s);

Only one legume type in a rotation;

Only same legume in legume-maize-legume combination;

Sweet potato is only grown during the long rain season.

Description of *Rweya* activities

The *Rweya* provides mulch for the *Kibanja*, and livestock feeds through either direct grazing or cut and carry system. In this study, grass was regarded as crop because of the functions mentioned above, i.e. often harvested for mulching purposes for the *Kibanja* or grazed directly by cattle or collected as fodder for feeding the livestock in the stable.

Description of livestock activities

Livestock is an important component in Bukoba farming system and is linked to crop activities. Animals kept by farmers in this system include cattle, goats, pigs, and chicken. However, cattle and goats were the animals considered in the model because are the most land binding animals in the system. These were converted to Tropical Livestock Unit (TLU) using a standard unit usually based on live weight of one mature zebu breed cattle with 250 kg, although there are variations in their computation (Pratt and Gwynne, 1977; Field and Simpkin, 1985). The conversion factors used were: zebu cattle (1 TLU), and goat (0.17 TLU) (Frantkin and Roth, 1990; Otte and Chilonda, 2002; Akresh and Verwimp, 2006). In case of non grazing dairy cattle, a 1.6 TLU was considered which are generally managed under zero grazing system.

Two feeding systems for livestock were defined namely free grazing system and stall feeding system. Main outputs from livestock are manure, meat, and milk. Manure is applied in the crop fields to replenish soil nutrients. Meat and milk are consumed within the household and some sold to the market to earn income (Figure 4). However, since manure production is the main farmers' objective for keeping livestock in the farming system, therefore, manure was regarded as output in livestock activity. Milk production is also an important output in dairy cattle that are managed under zero grazing system, but were not considered in this model.

Feed requirements and supply to animals, therefore, can be met from among four sources: 1) native *Rweya* grass, 2) crop residues including herbaceous legumes, 3) *Kikamba* weeds, and 4) concentrates – maize bran and seed cakes. The type and quality of feeds determines the amount and quality of manure. Therefore, constraints were given in the model for maximum amount of feed in the farm available in terms of dry matter production for livestock feeding. Table 5 shows different feed sources, their digestibility and N-content which were all used in the computation of manure production. Forage requirements by cattle represented by mature zebu (1TLU) which graze in the *Rweya*, was estimated to consume 6.25 kg DM and 0.15 kg of digestible protein daily, equivalent to annual requirements of 2300 kg DM and 57 kg of digestible protein (Le Houerou and Hoste, 1977; Stéphenne and Lambin, 2001). It is estimated that a maximum of 30 per cent of grasses on offer in the *Rweya* are grazed during the year-round (de Ridder and Breman, 1993). The rest are harvested as fodder (10%) meant for cut and carry system for dairy cattle, and the remaining (60%) is used as mulch in the *Kibanja*.

In feeding dairy cattle, the DM intake depends on body weight, milk yield, stage of lactation and pregnancy of the cow. In this study, we estimated DM intake at 3% for an animal with 400 kg body weight (1.6 TLU) producing 10 kg of milk per day, would need 9.2 kgDM day^{-1} and 0.22 kg of digestible protein daily equivalent to 3358 kg DM yr^{-1} and 80 kg yr^{-1} of protein (Chamberlain and Wilkinson, 2002).

Table 5: Feed materials and their respective digestibility and N-content values

Fodder material	Digestibility (% of DM)	N content (g kg^{-1})	References
Native *Rweya* grass	34	16	Research data, 2011
Maize bran	70	53	Mlay, *et al*., (2006)
Sunflower seedcakes	61	27	Mlay, *et al*., (2006)
Kikamba weeds	34	12	Mwita (2003)
Maize stover	49	6	Kabatange and Shayo (1997)
Sweet potato residues	63	14	Mwita (2003)
Residues of *M. pruriens*	62	35	Palm *et al*, (1997)
Residues of *M. axillare*	64	32	Mwita (2003)
Residues of *M. atropurpureum*	68	32	Mwita (2003)
Residues of *D. intortum*	56	32	Mwita (2003)

Manure output was estimated using the relationship described by Lascarno et al., 1992 (cited by Baijukya, 2004) as:

Manure produced (kg) = $DM_{ingested} - D\left(\frac{DM_{ingested}}{100}\right)$……………..……………… (9)

where: $DM_{ingested}$ = dry matter of feed materials (kg) ingested and D = digestibility of feed materials (%). Activities considered in the model are summarized in Table 6

Table 6: Definition criteria and distinguishing variants per criterion of land use and livestock activities for MGLP model

Activities	Definition criterion	Maximum number of variants
Kibanja	Crops grown	2 (banana, coffee) present in the field for whole year round
	Fertilization techniques	4 (grass mulch, manure-non-grazing, manure- grazing, legume mulch)
Rweya	Grass uses	3 (free grazing, fodder cutting, mulch)
Kikamba	Crops for rotation	8 (sp, maize, Ltc, Lcg, Lm, Lma, Lmat, Ld)
	Uses of crop residues	3 (fed to livestock, applied in *Kibanja* as mulch, incorporated in the soil)
	Rotation seasons	4 (SR1, LR1, SR2, LR2).
Livestock	Type of management	2 (free grazing, stall feeding)
	Animal products	1 (manure)
	Forage types	7 (native grass, maize stover, Sp residues, Lm, Lma, Lmat, Ld)

Data analysis

All data collected from the field and those mined from archives were subjected to the General Algebraic Modeling System (GAMS) for optimization of the research objectives.

Objectives functions

Based on main research problem referred to in this study that is associated with land use in the farming system i.e. decline system productivity; the objective functions for this study were linked to ecological imbalance and maintenance of sustainable productivity of the *Kibanja* subsystem, thus: to maximize *Kibanja* productivity in relation to *Rweya* and *Kikamba* activities; and to optimize the nutrient balances for Nitrogen (N) and Potassium (K). The mathematical optimization was done using General Algebraic Modeling system (GAMS) model.

Indices:

Different land use activities (*LUA*) were considered as decision variables in the model. These activities were defined as crop or livestock production on a given area of land according to farm type characterized by inputs and outputs for each activity, given one hectare of *Rweya* land. The indices included crop code (*c*), *Kibanja (KB),* land type (*LT*), in different seasons (*sn*), rotation codes (*R*), labour type (*lb*), and main working periods (*wp*); area of respective land used in ha (*x*). Inputs and outputs of all activities were quantified using data collected from field survey and calculations based on target oriented approach (Ittersum and Rabinge, 1997). All calculations were based on major farming seasons, i.e. long rain (LR) and short rain

(SR) seasons, thus a time frame of four seasons (two years) were considered (Figure 5).

Constraints and free variables

The Land

Land areas for the *Kibanja*, *Kikamba_Rweya* were considered as constraint in all farm types. The *Kibanja* area occupied by crops (bananas and coffee) must be equal or less to the available *Kibanja* area. In this case the available areas were 0.8, 0.6, and 0.4 ha being mean values for FT1, FT2, and FT3, respectively. Moreover, a certain area from the *Kikamba* or *Rweya* must be allocated in every LR season per household that is sufficient to produce at least 50 kgDM of sweet potatoes for food security reasons, thus constraining the available land for production of mulch, cultivation of other crops, and keeping cattle. Free variables in the model were nutrient balances, manure production, and mulch production. These are considered as output from the *Kikamba* or *Rweya* because manure is produced for the *Kibanja*. Area of *Kibanja* for crop activities in every season was fixed for every farm type.

$$\sum_a vKBx_{KB\_LUA,KB\_C,a,sn-1} = \sum_a (vKBx_{KB\_LUA,KB\_C,a,sn}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots\ldots\ldots(10)$$

where *a*=nutrient source (mulch, manure, herbaceous legumes, or crop residues)

Area of *Kibanja* land used in a season:

$$\sum_{KB\_LUA,a} vKBx_{KB\_LUA,KB\_b,a,sn} \leq TF_{KB} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots\ldots\ldots(11)$$

However, bearing in mind that crops in a *Kibanja* are architecturally arranged such that two third of *Kibanja* is under banana monocropping while one third is a mixture of banana and coffee, thus *Kibanja* activities is expressed as:

$$\sum_{a} vKBx_{b,a,sn} + vKBx_{B,a,sn} = KB\_ratio * \sum_{KB\_LUA,C,a} \left(vKBx_{KB\_LUA,KB\_C,a,sn} \right) \text{……………....(12)}$$

where *b*=banana1, *B*=banana2, *TF*=total farm size, *c*=crop code; *a*=nutrient source

Area of *Kikamba* is reserved during long rain season which is sufficient to produce at least 50 kg DM of sweet potato (ha):

$$vKK_{sn} = \sum_{R} vKKx_{R} \text{ …………………………………………..……………….(13)}$$

Area of *Rweya* used in a season (ha):

$$vRW_{sn} = \sum_{TLU\_A,RW\_c} vRWx_{TLU\_A,RW\_C,sn} \text{ ……………………………….………………….(14)}$$

Total area (ha) of *Kikamba and Rweya* used in a season (farm size) is expressed as:

$$(vKK_{sn} + vRW)_{sn} \leq TF_{KK\_RW} \text{ ; TF= total farm size (1 ha) ………………………..(15)}$$

Whereas the *Kibanja* area in the mixture of banana and coffee for every season was expressed as:

$$vKBx_{KB\_LUA,a,sn} = vKB_{KB\_LUA,a,sn} \text{ ……………………………………….……………..(16)}$$

Yield

Sweet potato yield in the *Kikamba* per season:

$$\sum_{R} (KK\_yield_{R,sn,sp} * vKKx_{R}) \geq KK\_yield\_SP_{sn} \text{ for } \forall\ sn \text{ …………………..…..(17)}$$

Where: *sn* = seasons; *R*=Rotation code; *Sp* = sweet potato; *v*=variable

***Kikamba* output:**

$$vKK\_yield_{R,sn} = vKK\_yield_{R,sn} * vKKx_R \quad \text{……………………………………….(18)}$$

Total yield in the *Kibanja* is provided in the equation*:*

$$vKB\_yield\_a_{KB\_C,a,sn} = \sum_{KB\_LUA} (vKB\_yield_{KB\_LUA,C,a,sn} * vKBx_{KB\_LUA,C,a,sn}) \quad \text{………(19)}$$

Kibanja yield per crop activities is expressed as:

$$vKB\_yield_{KB\_C} = \sum_{a,sn} (vKB\_yield\_a_{KB\_C,a,sn} * vKBx_{KB\_LUA,C,a,sn}) \quad \text{………………..(20)}$$

Rweya yield for crop activities (grass) is provided by:

$$vRW\_yield_{RW\_C} = \sum_{TLU\_A} (vRW\_yield_{TLU\_A,RW\_C,sn} * vRW\_X_{TLU\_A,RW\_C,sn}) \quad \text{……....(21)}$$

Nitrogen balances

Nitrogen balances for each rotation in the *Kikamba* are expressed as*:*

$$vKK\_N_R = KK\_N_R * KKx_R \quad \text{…………………………………………………..(22)}$$

Total N balance

$$vKK\_N = \sum_{R} (KK\_N_R * vKKx_R) \quad \text{……………………………..………………(23)}$$

Nitrogen requirement in the *Kibanja*

$$vKB\_N_{sn} = \sum_{KB\_LUA,C,a} KB\_nutrients\_IN_{KB\_LUA,a,N,sn} * vKBx_{KB\_LUA,KB\_C,a,sn} \quad \text{….…....(24)}$$

Nitrogen production from *Kikamba* residues

$$vKK\_N_{sn,op} = \sum_{R} KK\_\mathrm{Re}s\_N_{R,sn,op} * vKKx_{R} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(25)$$

Nitrogen production from *Rweya* resources

$$vRW\_N_{sn} = \sum_{TLU\_A,RW\_C} RW\_nutrients_{TLU\_A,RW\_C,N,sn} * vRWx_{TLU\_A,RW\_C,sn} \quad \ldots\ldots\ldots\ldots..(26)$$

f) Nitrogen balance in the *Kibanja* per season:

$$vTLU\_N\_manure_{sn} + vRW\_N\_mulch_{sn} + \sum_{op} vKK\_N\_mulch_{sn,op} \geq vKB\_N\_need_{sn} \quad \ldots\ldots(27)$$

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Tenure systems and soil fertility management

Land acquisition and cropping system

The acquisition of land in Bukoba takes several forms. Although inheritance through paternal lineage was already the dominant means of acquisition to land before and in 1960s, there were also other forms of land possession such as purchase, gifts from the chief or relatives, and renting. However, this study found that 74% and 39% of the interviewed households in the high rainfall zone (n=74) had acquired *Kibanja* and *Rweya* lands, respectively, through inheritance (Table 7). Other means of land acquisition including allocation by village government, leasing, renting, has now diminishing but purchase of *Kibanja* land is still important, as it was before and in the 1960s. A significant change is observed for *Rweya* land that gained significant market value in recent years such that about 24% and 30% of the respondents in the HRZ and LRZ, respectively had purchased the *Rweya* during this study (Table 7).

Table 7 : Changes in means of land acquisition of *Kibanja* and *Rweya* by households among the respondents (%) in two villages of Bukoba District, in 1965 and 2005

Means of land acquisition	Butahyaibega (HRZ)			Butulage (LRZ)
	Kibanja		*Rweya*	*Rweya*
	1965(n=53)[a]	2005(n=74)[b]	2005(n=74)[b]	2005 (n=77)[b]
Inheritance	30	74	39	16
Purchase	13	12	24	30
Gift from relative	13	0	0	0
Tenant from landholder	13	0	0	0
Tenant by inheritance	13	0	0	0
Contract tenant	8	0	0	0
Gift from the chief	6	0	0	0
Gift from landholder	2	0	0	0
Inherited /purchased	2	14	3	0
Allocation by village	0	0	4	6
Renting	0	0	11	10
Do not have	0	0	19	38

Source: [a]Reining, 1967; [b]Mwijage *et al*., 2011

About 69% of the farmers in Bukoba do not own *Rweya* land privately, and 79% of the interviewed farmers who own the *Rweya* privately had plantated trees (Table 8). The distribution of *Kibanja* size differs considerably among households in the high rainfall zone and the low rainfall zone areas. While it is only 12% of farmers in the HRZ have *Kibanja* exceeding 1.1 ha, it was found that about 40% of farmers in the LRZ owned *Kibanja* larger than 1.1 ha. The implication of *Kibanja* acreage is reflected in the manure and mulch requirements for respective farming families. However, for the *Rweya* that is owned privately, it was 4% and 3% for farmers having above 1 ha in the HRZ and LRZ, respectively (Table 8). This is due to the relatively high population density in the HRZ.

Table 8: Land use in Bukoba District and the area owned by farmers (ha) among respondents for different land use types

Land use type	Land area (ha)	Number of households (%) with respective range of land area owned and trees plantation in the *Rweya*		
		HRZ (n=74)	LRZ (n=77)	Overall (n=151)
Kibanja	Nil	nil	Nil	Nil
	0.1 - 0.5	47	33	40
	0.51 - 1.0	41	27	34
	1.1 - Above	12	40	26
Kikamba	Nil	27	40	34
	0.1 - 0.5	55	44	50
	0.51 - 1.0	15	8	11
	1.1 - Above	3	8	5
Rweya	Nil	74	63	69
	0.1 - 0.5	16	30	23
	0.51 - 1.0	5	4	5
	1.1 - Above	4	3	3
Trees plantation	Nil	77	80	79
	0.1 - 0.5	15	17	16
	0.51 - 1.0	4	0	2
	1.1 - Above	4	3	3

Roles of grassland on fertility management in relation to tenure system

Traditionally, the *Rweya* was the land reserved for grazing and cultivation of seasonal crops that do not demand high fertility of soils through shifting cultivation system. At present, the large portion of *Rweya* is mainly occupied by trees. Some farmers are expanding cultivation of bananas into the *Rweya* following population growth and land shortage. The *Rweya* also provides off-farm employment and income generating opportunities such as collecting and selling mulch grass and carpet grass.

Simultaneously, cattle form an integrated part of the farming system and are important for concentrating nutrients from the *Rweya* to the *Kibanja*. In old days, grazing in grasslands was centrally regulated by appointed person by villagers known as *'mkondo',* who was responsible to select grazing sites, supervise cattle herders, monitoring and isolation of diseased animals (Lorkeers *et al*., 1996). Such centralized control suggests that, despite its poor soil fertility, the *Rweya* land was valued for its capacity to sustain the productivity of the *Kibanja* through exporting nutrients in the form of mulch and manure.

Another important use of *Rweya* of this farming system was shifting cultivation for what is termed locally as *Omusiri* system. To ensure for long term productivity, in the past, the land would be left fallow for 6-8 years to allow the soil to regenerate. Such shifting cultivation in the *Rweya* was controlled by the traditional chief through male or female overseers known as *Omuharambwa* who made sure that people abided to the rules of cultivating *Omusiri.* Thus, in order to cultivate one hectare with annual crops, a farmer would need 8 hectares of grassland and about 75% of households was estimated to cultivate *Omusiri* in the 1960s (Rald and Rald, 1975). During the fallow period, the *Rweya* could only be used for cattle grazing and grass cutting for mulching, thatching, and home carpeting. After the *Rweya* was fully regenerated, *Omuharambwa* reported to the chief who would allow people to use that piece of land again for *Omusiri* cultivation.

Historical development of tenure systems and cropping pattern

In the late 1880s, there was an outbreak of rinderpest that killed about 90% of all cattle in the District. Consequently, the pastoralist way of life became untenable (Steenhuijsen Piters, 1999). Having lost their source of wealth, the pastoralists were forced to re-orient towards crop production. Although their experience in farming may have been limited, their cattle-based wealth had yielded them considerable political power. It was during this time when a new feudalistic form of land tenure known as *Nyarubanja* (large banana plantation) is believed to have emerged in Bukoba. However, the actual origins of this form of tenure remain conjectural, based on interpretations from court proceedings and chiefs belonging to the ruling clans (Pokorny, 1973). The *Nyarubanja* lands were controlled by the chief who could allocate it to individuals of the ruling elite, leaving the former owners as tenants, obliged to pay tribute to the new owners.

Although the emergence of the *Nyarubanja* system meant a discontinuation of co-evolution of tenure and land use and drastically altered property and labour relations on the affected farms, its significance as a distinct land tenure system should not be overestimated. First, *Nyarubanja* did not compromise the structural links between different land use types of the Bukoba farming system. Nutrient transfers between different land use types were maintained, albeit now by cattle owning tenants. Second, *Nyarubanja* tenure was of little significance in comparison to customary tenure arrangements. By the end of 19^{th} century, it was estimated that the *Kibanja* under *Nyarubanja* tenure occupied about 10% of the total *Kibanja* area whilst the rest remained under customary tenure arrangements (Kalikawe, 1974).

Besides *Nyarubanja*, freehold tenure was introduced in Bukoba as the territory that currently comprises mainland Tanzania became incorporated into the German empire in 1885. Characterised by a complete and unrestricted entitlement to the land, the freehold system served to facilitate European farmers' settlement and investment in agriculture. However, such new tenure arrangements had limited impact in Bukoba because its inhabitants had been given usufruct rights for large parts of land that was treated as 'un-owned' (URT, 1994). However, freehold land tenure comprised a mere 2% of the arable land area in the District (Mutahaba, 1969). Its introduction, therefore, hardly affected the existing *Nyarubanja* and customary tenure arrangements, and these tenure forms remained unaltered during both the German and the succeeding British colonial administration (Mutahaba, 1969).

While new tenure arrangement was introduced during the colonial period, also new cash crops notably coffee (during second half of 19^{th} century) and tea (in 1950s) which had impact on land use were introduced. Since coffee was a perennial crop, its introduction reinforced for the development of continuous cultivation and permanent settlement of farming households on the *Kibanja*. However, tea was only grown in estates at the beginning occupying about 365ha, which is a relatively small area in the District. Later in the 1960s smallholder farmers were involved in tea farming whereby each farmer was allocated about one third of a hectare of *Rweya* for tea cultivation occupying a total of 1245ha. The cultivation costs and important inputs were provided by the state, thus marking the appropriation of communal *Rweya* by outsiders - the state. As matter of fact, the introduction of such cash crops contributed to the commoditization of land as Cory and Hartnoll (1945), states: "…sale of land in Bukoba was practically unknown until within the last forty years and therefore there were no rules under customary laws to deal with it."

Although the existence of *Kikamba* land is tied up with the *Kibanja* and was there for long time past, its significance and use increased with time in response to declining productivity of the *Kibanja.* Therefore, in the context of this discussion, as coping strategies, farmers were compelled to cultivate sweet potato in rotation with maize in the *Kikamba* as the *Kibanja* failed to produce adequate bananas, the staple food of farming families. To substantiate this, an elderly farmer narrates:

> "During the old days when the *Kibanja* was still productive, we were not eating *emyaka* because people would as much as possible avoid contemptuous attitude from neighbours being regarded as a hunger stricken household" (Elesi, 2006, Bukoba farmer – personal communication).

To summarize, up to the end of the colonial period new tenure arrangements had been introduced in Bukoba District, yet their impact on the ground remained limited because only a small proportion of the land was affected by these new tenure systems. However, rather than changes in land tenure systems, there was incorporation of the area into colonial economy and the introduction of new cash crops (coffee and tea) that changed Bukoba's agricultural economy and smallholder farmers' land use practices (Rald and Rald, 1975). Such changes did not, however, end the long established structural link between *Kibanja* and *Rweya* lands.

Population pressure induced tenure change

Below, we first show how population growth drove both the fragmentation of *Kibanja* lands and expansion of *Kibanja* and *Kikamba* lands at the expense of *Rweya* land. Both developments reduced rural households' capacity to make their living from the land, and forcing many into non-agricultural income earning activities. The population increased in the District from 125,000 in 1967 to 290,000 in 2007 (up to 233% in forty years) might also have contributed to a decline in system productivity because available grass cannot satisfy the ever growing demand. This comes from the fact that establishment of one acre (0.4 ha) of new *Kibanja* on poor *Rweya* soils needs 16 tons of mulch for the first time, followed by 8 tons every year continuously to maintain the standard productivity (Rald and Rald, 1975).

Figure 8 demonstrate how the area under *Kibanja* and *Kikamba* expands at the expense of *Rweya* lands since new *Kibanja* get established on the *Rweya* following increasing population density while experiencing shrinkage of the area under *Rweya*. In addition, average *Kibanja* size per farming family declined slightly according to available evidence (Table 9). Two reasons, can account for this limited subdivision of *Kibanja* to smaller plots: First, the habit of purchasing the land which was already common in the 1960s, mitigated further land fragmentation (Table 7). Second, the inherent land inheritance system in Bukoba society slowed-down the subdivision of land in some families where only one son inherits the portion of the *Kibanja*, forcing other siblings (who only get a token share) to out-migrate or seek for non-agricultural sources of income. Since *Rweya* land resources were characterised by communal control, the productivity of the farming system was sustained.

Table 9: Average *Kibanja* size per household estimated in different studies from 1984 through 2005 for selected Wards in Bukoba District*

Ward	1984[a]	1997[b]	2005[c]
Kanyangereko (HRZ)	n.a	0.6 (120)	0.5 (74)
Izimbya (LRZ)	1.8 (20)	n.a	1.6 (77)
Source	[a]Tibaijuka (1984)	[b]Nkuba (1997)	[c]Mwijage *et al.*, 2009.

* In parenthesis denotes sample size on which the measurements were based in the respective years. n.a: not available in the respective years

The demand for cattle manure has also increased as farming population increased. Table 10 illustrate the number of farming households and those with cattle in Bukoba between 1958 and 2002. However, the proportion of households owning cattle declined almost by half during same period. This implies that few households tend to have more cattle (4 heads in 1958 to 7 heads in 2002) than in the past thus facilitate social differentiation among cattle owner households in terms of farm productivity. In fact, households lacking cattle tend to have more *Omusiri* plots hence termed as *Omusiri*-dependent households; while those with enough manure have a tendency to rely more on *Kibanja* and are less reliant on *Omusiri* hence termed as *Kibanja*-specialized households (Maruo, 2002). If the level of nutrient transfer from the *Rweya* to the *Kibanja* is to be sustained, therefore, increasing cattle population is therefore necessary. However, this is constrained by the availability of grazing land.

Table 10: Cattle ownership per households in Bukoba District from 1958 to 2002

Year	Number of households	Number of cattle	Households with cattle (%)	Average household size	Source
1958	62924	50339	20	4	Rald and Rald (1975)
1967*	101440	78000	14	5.4	Rald and Rald (1975)
1978*	73253	84176	13	5.5	MALD (1984)
2002	90502	65849	11	6.8	NBS (2002)

* Between 1958-2002 years the District was split into two namely Bukoba and Muleba because of increased population; NBS: National Bureau of Statistics.

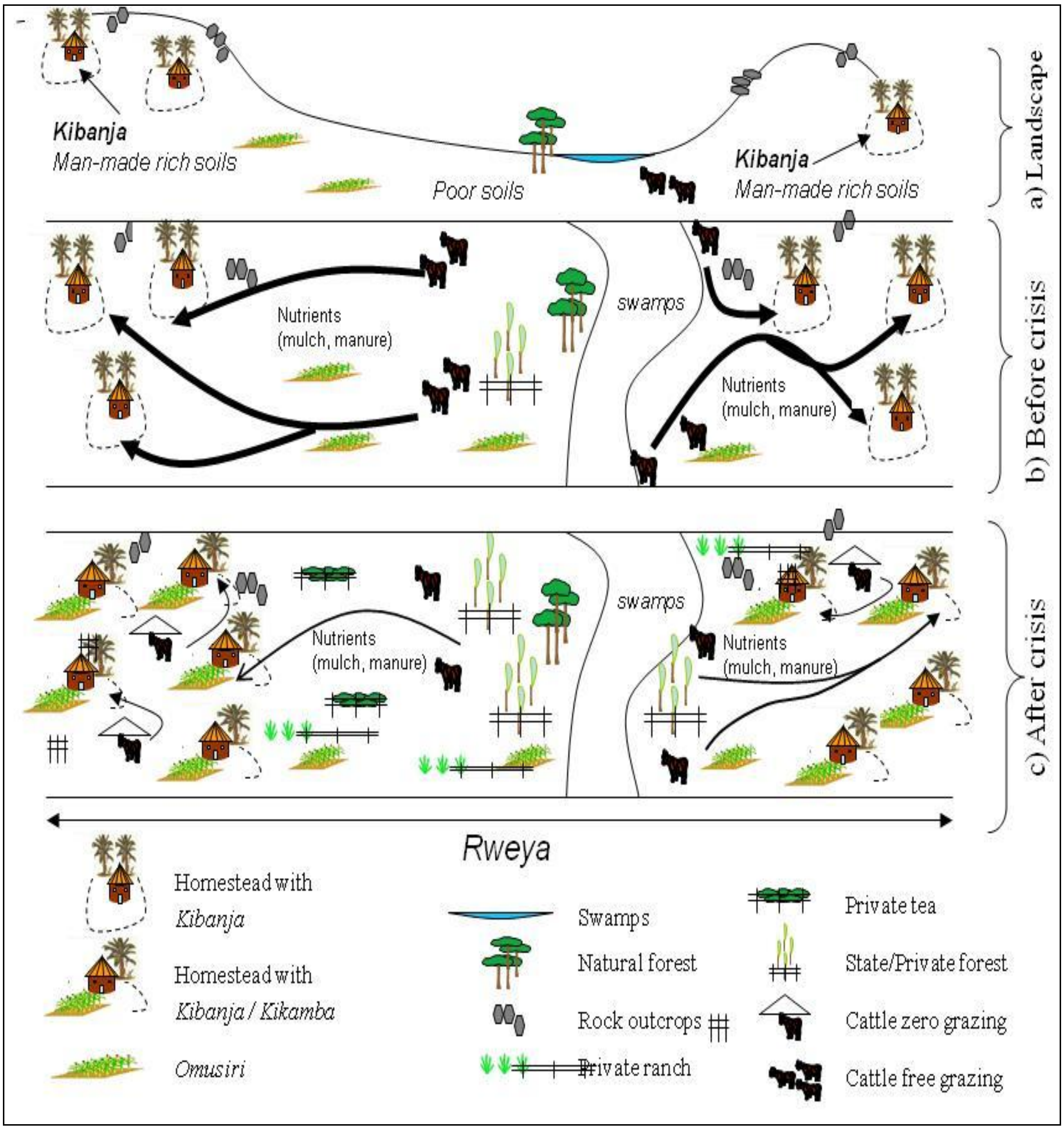


Figure 8: Simplified scheme of structural relations among basic land use types and intensity of nutrient flows before and after the productivity crisis in the banana-based farming system indicating (a) Cross section arrangement of the landscape; (b) Thick arrows signifying the intensity of nutrient transfer among land use types; and (c) The current state of nutrient flows

Socio-economic forces of tenurial change

Traditional land tenure systems, as hypothetically outlined in the previously section were by this time already undergoing modifications. For example, through the replacement of hereditary chiefs by appointed territorial authorities. Moreover, the introduction of perennial crops and technological improvements facilitated for agriculture development in terms of making more permanent settlement and more profitable farming. Growing of cash crops (coffee and tea) offered further possibilities for individual exploitation. The rising shortage of land and various investments in improvements imputed a more functional and commercial attitude towards land, and a monetary value for *Rweya* increased tremendously to a tune of more than 400% between 1985 and 1995; and by 180% between 1995 and 2005, despite its inherent poor quality of this landuse type (Table 11). However, previously the *Rweya* was considered as free good to all farming community members but in recent decades, these lands are grabbed by local wealthy and or politically powerful individuals.

Over the same period, community control over land has tended to decay. In some villages where little land are available for allocation, often the rights of allocation that is vested to political leaders on behalf of the community are seldom exercised. The unprecedented increase in population also has tended to build a closer personal identification with a specific area of land in the *Rweya* and to promote the spread of more intensive methods of land use. Thus the interdependence of traditional society has been found increasingly incompatible with evolving market economy. At the same time, power went away from the traditional chieftainship towards elected councils and educated elites: rights of control over land were increasingly divorced from the other powers and responsibilities of chieftainship; and traditional relationships were further eroded by the acquisition of new skills and development opportunities.

All these internal changes were related to, and deeply affected by socioeconomic development among the community that acquired different attitudes towards land, and different views on cultural transformation. Farmers developed ideas that land is a fully negotiable commodity that all land must be owned by someone, and that individuals rather than communal ownership of land is the cornerstone of a progressive society. Thus, with time the customary land tenure arrangements were increasingly undermined by socio-economic and political changes. In some instances, the customary tenure systems were condemned as inefficient, and blamed as potential catalysts to capitalist class formation if allowed to evolve on their own (Nyerere, 1967). In his article titled *–The Basis of African Socialism* (1967), President Nyerere explicitly states:

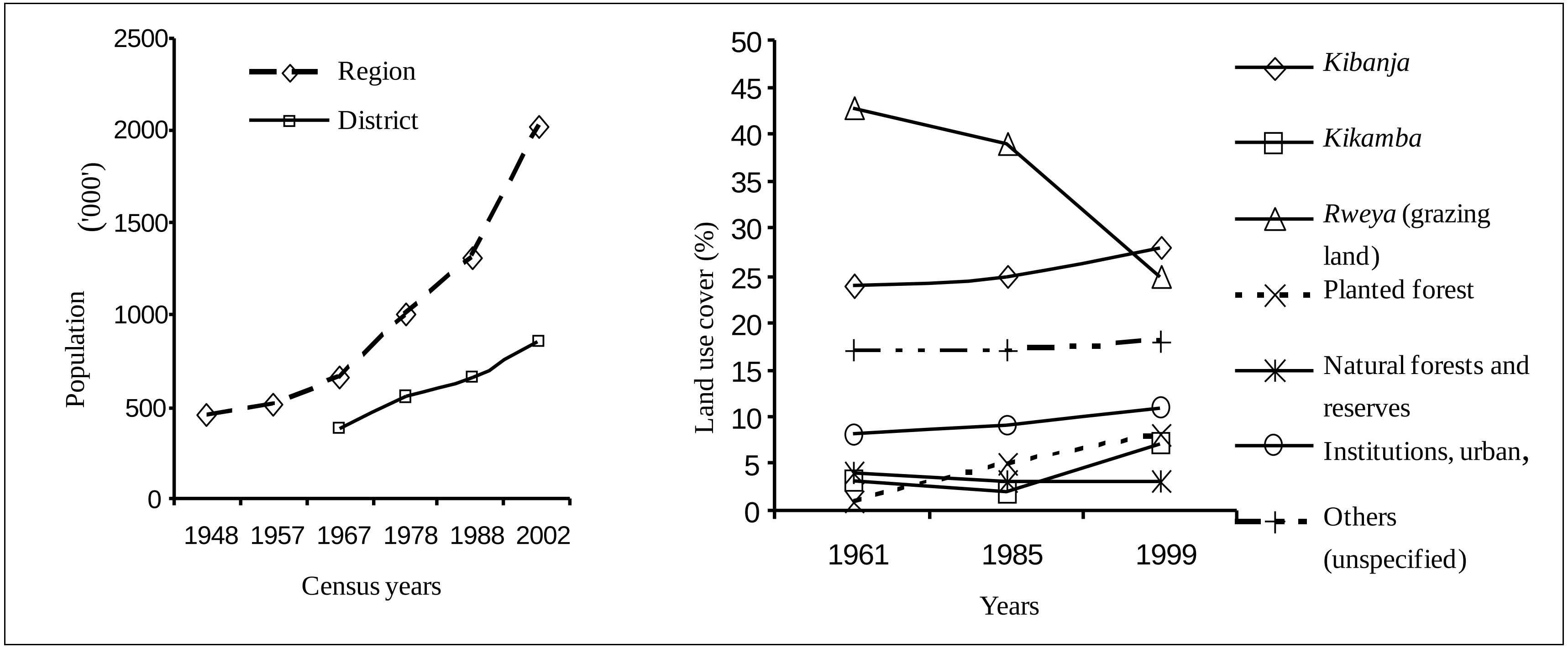
> "The TANU government must go back to the traditional African custom of land holding. That is to say, a member of society will be entitled to a piece of land on condition that he uses it. Unconditional or freehold ownership of land (which leads to speculation and parasitism) must be abolished".

Table 11: Estimated market value in Tanzanian shillings ('000 ha^{-1}) for *Kibanja* and *Rweya* in Bukoba District, 1955-2005[1]

Land use	1955[a]	1965[a]	1975[a]	1985[b]	1995[b]	2006[b]
Kibanja	3	5.42	10 (1.4)	25 (0.62)	496(1.05)	1270 (1.47)
Rweya	-	-	-	1.26 (0.03)	62.5(0.13)	200(0.23)

[1] Values in parenthesis indicate US$ equivalent during the respective year.

Sources: a) Rald and Rald (1975); b) based on discussion with elderly farmers (n=4), Bukoba, 14 July 2006.



(a) (b)

Figure 9: a) Population growth for Kagera region and Bukoba District under the same land area; and (b) Relative proportion (%) of different land use in Kyamutwara division, 1961 - 1999. (Source: a- Bureau of statistics; and b- After Baijukya *et al.*, 2005)

During socialist-inclined government, all lands in Tanzania were declared government properties vested in the president following the principles of Arusha declaration of 1967. During this time, the *Nyarubanja* and the freehold land tenure system was abolished and thus, somewhat reduced the land use rights of farmers. The nationalisation of land was followed by Tanzania's infamous "Operation *Vijiji*" of 1976 whereby people were resettled into *Ujamaa* villages where the land would be worked communally. In Bukoba District and other areas in the country with perennial crops and permanent settlement, the situation was slightly different. Villagers were not resettled, but required to create communal farms in what were considered to be 'open areas', the *Rweya.* As a result, traditional arrangements were disrupted. As we argued before, the land reforms during Nyerere's government meant that the administration of *Rweya* land was transferred from traditional chiefs to village development committees following the abolition of chiefdoms. In doing so, the capacity of ordinary villagers to regulate the use of communal resources was reduced. Village Development Committees became the administrative organ for allocating unoccupied land formerly vested in the chiefs but now claimed by the government. They also provided a link between political and administrative institutions rather than intervening directly. The role of the *Mkondo* and *Omuharambwa* diminished gradually, destabilizing the traditional mechanism that regulated the use of *Rweya* lands. Consequently, there was lack of regulatory mechanism of land use that was basis for rapid degradation of the *Rweya* such as uncontrolled fallow periods for *Omusiri* cultivation resulting to low productivity on those plots.

During the second phase government after 1985 onwards, there was a comprehensive village land registration programme with intention to survey and demarcate village borders. Thus, a single right of occupancy was proposed for an entire village (including the *Rweya* land). In Bukoba, this land titling policy was most evident in the 'open' areas - the *Rweya*, where individuals were gradually increasingly claiming those areas especially those with economic and political influence. The claimants started planting trees, setting institutions, or establishing private ranches (Figure 8). In doing so, the earlier roles of *Rweya* as a major source of nutrients for *Kibanja* through provision of grass and manure were gradually replaced by new uses. Figure 9 illustrates relative land cover of different land use types and their dynamics in Bukoba District within recent decades. The figure indicates a rapid decline of the area cover under the *Rweya* over the last 40 years from 1961 to 1999. It must be emphasized that the absence of an effective regulatory mechanism constrains smallholder farmers' access and use of *Rweya* as women interviewed while cultivating *Omusiri* elucidate:

> 'This season we requested the *Rweya* owner to cultivate Bambara nuts. However, we were only allowed to plant for this season only as the owner will plant trees after the crops are removed, and this is the trend year after year nowadays'

During the 1980s, there was public dissatisfaction with the government's land policies that triggered the formulation of the new land policy. In 1991, the then President Mwinyi appointed a commission of inquiry into land matters, mandated to review laws and policies and to make recommendations to the government for necessary reforms. Following the land commission's report, the National Land Policy (NLP) was formulated in 1995, followed by the Village Land Act of 1999. The policy recognizes a dual system of tenure i.e. the customary and statutory rights of occupancy and supports household farming through decentralized land administration at village level. Under NLP, individual title deeds are supposed to be issued by the village government for a piece of land they occupy after a formal application to the village council, whereupon the applicant is required to pay a fee. According to NLP, the title deed granted under this procedure is given equal status to that granted by the commissioner of lands responsible for issuing land titles in central government. The aim of this provision was to provide peasant farmers with tenure security so that their land could be used as collateral in financial institutions. However, of all interviewed farmers in this study (n=151), none had such a title for the land they owned, nor were they aware of the existence of such provisions, suggesting that the impact of the new land policy on tenure arrangements was limited. Apparently, tenure arrangements for *Kibanja* land are regarded as secure by the farmers, which contrast plainly with the tenure arrangements pertaining to the *Rweya* land.

In most villages, land grabbing is common and individuals involved are rewarded with strong, non-formal, individualized land rights, particularly in the *Rweya*. Field observations indicate that tree planting is done by farmers as economic venture and also as ways to legalize the ownership of land, thus imposing restrictions for access by rest of villagers. This contradicts the infamous claim that privatization of common land could potentially benefit the entire community (Lesorogol, 2005). In fact, this transformation is subject to unfair implementation by benefiting only few local elites. Although the NLP recognizes “communal village land”, and requires that any allocation to individuals must be blessed by the village assembly, in practice this rarely happens. Lacks of awareness of official policy documents and/or deliberate negligence by local actors are often the cause of this. Not surprisingly then, land conflicts are on the rise whereby communal access and individualized land rights clash just like elsewhere in Africa (Chimhowu and Woodhouse, 2006).

Then again, the decline of productivity in this farming system might have been aggravated by prevailing socioeconomic developments and changes that also have weakened the structural link between the *Kibanja* and *Rweya.* Among the three predominant tenure systems, the *Nyarubanja* system was abolished on grounds of its perceived exploitative features, whereas the customary and freehold tenure became officially allowed through formal legal rules. The recognition of customary rights did not, however, mean that local 'traditional' institutions could enforce them. The socialism (*ujamaa)* ideology for example undermined such institutions that had enforced customary tenure arrangements. Subsequently, ideological shifts in policy notably neo-liberalism did not abolish or introduce new forms of tenure, and they strengthened a tendency to privatize the previously communally accessed lands. Thus, government policy had an indirect effect on land use change in the farming system as illustrated in Figure 8 showing how nutrient transfers from the *Rweya* to the *Kibanja* lands have declined emanating from changes in land use resulting from population pressure and socioeconomic developments.

Impact of tenure changes on cropping patterns and farm productivity

One criterion for gauging the social implications of land tenure change is productivity. At the initial stages of any land reform there is a likelihood of a decline in productivity due to instability and apprehension on the part of the farmers, the former landlords, and the governing class, who have to provide essential supportive services and guidelines.

As the *Rweya* land in the Bukoba farming system became under control of individuals, tensions and disputes arising from competition for available land resources have been growing. Restriction of access to such resources has had negative impacts on the productivity of home gardens (*Kibanja*) which heavily depend on soil organic matter (Bationo *et al.*, 2007). Table 12 compares average productivity for selected crops over time signifying a general decline in productivity for all selected crops, except tea (*Camellia sinensis*). In this farming system, the productivity of tea plantations depends on subsidized mineral fertilizers through a tea company which, during the reporting period was distributing farm inputs to farmers for their plantations. This arrangement did not apply to other food crops, thus explains why tea productivity is not affected by changes in tenure systems during the said period. However, up to the 1980s, farmers in Bukoba obtained cash from sale of mainly coffee and tea (Smith, 1984). Falls in sale prices of these crops in the world market during this period led to some farmers to abandon their coffee and tea plantations, thus making the land less productive. Besides, the continued decline in banana production led to crops like maize, cassava, and sweet potato to gain more importance as food crops and as alternative sources of income for farmers.

Moreover, increased demand for wood as source of fuel energy and construction materials also encouraged establishment of more trees on the *Rweya*. The link between the productivity of *Kibanja* and the tenure system, therefore, is in this case established through tenure arrangements that hinder farmers' accessibility to *Rweya* resources that are essential for soil fertility replenishment.

Table 12: Estimated productivity for selected crops at two periods (kg ha^{-1}yr^{-1}) in the three main land use types in the HRZ, Bukoba District

Period	*Kibanja*		*Kikamba*		*Rweya*	
	Banana	Beans	Cassava	Potatoes	Bambara nuts	Tea
1960-1980	13188[a]	450[a]	6682[d]	11702[d]	1500[d]	661[e]
1990-2000	2400[b]	125[c]	4843[d]	7888[d]	1371[d]	830[f]

Source: a: Rald and Rald (1975) measurement on average 0.26 ha *Kibanja*
b: Mbwana *et al*., (1997); based on surveys and measurements (n=180)
c: FSR, (1990), based on household surveys (n=120)
d: Mwijage *et al.*, (2009) data based on farmers' estimates (n=5)
e: NEI, (1994), data based on factory records
f: Wijnalda, (1996); data based on factory records of farmers' sales

It must be emphasized here that landlessness in Bukoba was rare prior to 1970s (Ilife, 1979). However, since then, it is getting common in recent years due to increased population pressure. Simultaneously, *Kikamba* lands have gained relative importance among farming households for food crops production because the crops grown in the *Kikamba* are annuals that allow short term flexibility in mitigating the complexity of tenure problems. Maize for example, is increasingly planted in the *Kikamba* in rotation with sweet potatoes compared to some decades ago when *Kikamba*-based maize was almost non-existent. At the moment, landless farmers and those with insufficient land and manure, tend to rent *Kikamba* from neighbours for growing maize or sweet potatoes, or cultivate *Omusiri* in the *Rweya*. When renting *Kikamba*, the tenants are usually not allowed to apply mineral fertilizer, due to wrongly conceived perception among landowners that mineral fertilizers spoil the land, reducing its long-term productivity, as per the confirmation by a farmer found growing poor maize field in the 2006/7 season who recounts as follows:

> ‘Look here *mtaalamu* (expert), I rented this plot from *Mzee* Yona with condition that I can plant maize so long as no mineral fertilizers are applied in his land; so I should abide to his condition so that I can be allowed to cultivate here next season’ (Mr. Ishengoma, 2007- personal communication).

Non-use of mineral fertilizers emerged during the 1970s when farmers were supplied with fertilizers special for tea plantations, which, apparently, some farmers applied this fertilizer in the banana fields exceeding the recommended rate that resulted in soil acidification in those fields. Since then, most farmers felt that inorganic fertilizer has detrimental effects on their soils. From above empirical evidence and field observations, the effect of complexity of tenure systems in Bukoba case is reflected in limited rational supply of inputs for rented land, resulting to poor productivity per unit of land.

The productivity of major crops indicated in Table 12 does not account for the quantity of used inputs for the realized outputs per hectare, and therefore may not be a sufficient indicator for the sustainability of the system. Hence, these data presents a sign for declining productivity for most important crops grown in the farming system. Explicitly, nutrient balances, i.e. net losses or gains of the most important soil nutrients on which crop growth depends, may provide a better understanding of sustainability of the productivity of the land. When the nutrient balances were calculated for *Kibanja* lands in selected farms, we realized that the *Kibanja* managed without adequate farm inputs of organic materials such as manure and mulch, were negative for important soil nutrients notably N, P, K, Ca, Mg, and S (Table 13), implying a threat to sustainability of the system.

Table 13: Nutrient balances (kg $ha^{-1}year^{-1}$) of *Kibanja* under different management levels in HRZ and LRZ of Bukoba[1]

Zone	Farm nutrient management level[2]	Nutrient balances					
		N	P	K	Ca	Mg	S
High rainfall zone	No cattle, no brewing	-76.2	-4.9	-50.0	-40.2	-26.8	-12.2
	No cattle, brewing	-73.9	4.2	-41.2	-39.8	-26.2	-12
	Indigenous cattle, no bedding	-7.5	10.8	-6.4	-13.9	-14.1	1.9
	Indigenous cattle, bedding	7.0	12.3	15.5	-10.9	-12.4	4.9
	Improved cattle under zero grazing	80.5	42.8	198.7	34.3	9.8	12.9
Low rainfall zone	No cattle, no brewing	-27.9	-2.7	-30.1	-6.5	-8.5	-3.9
	No cattle, brewing	-25.1	-2.0	-20.6	-4.8	-6.9	-3.8
	Indigenous cattle, no bedding	-8.7	1.6	-15.1	-1.6	-3.0	0.2
	Indigenous cattle, bedding	-3.9	2.4	-8.8	4.0	-2.3	0.7
	Improved cattle under zero grazing	11.0	8.9	32.1	12.5	2.4	5.0

[1]Source: Baijukya and Steenhuijsen Piters, 1998.

[2]Nutrient inputs into the farm is through organic resources mainly grasses as direct mulch from the *Rweya* or after other uses such as brewing - grasses used in brewing before application to the farm; and "bedding" - grasses put into cattle sheds for sometime to increase manure volume. Zero grazing is a practice where animals are fed while confined in stalls.

4.2 Typology of farming Households

Households' characteristics and variability

The participatory wealth ranking by the focus groups resulted in four resource groups (RGs) (Table 14). As commonly found in sub-Saharan Africa (Achard and Benoin, 2003; Green *et al.*, 2006; Zingore, 2006) farmers in Bukoba considered cattle to be an important indicator of wealth (Table 14). Livestock plays multiple roles such as provision of food, cash from sale of products, capital assets, provision of manure for cultivated crops, and others, thus shaping the farmers' social and economic well-being (Herrero *et al*., 2007; Zingore *et al*., 2007a). Other wealth indicators mentioned were: the quality of the house, owning transport facility, ability to educate the children, labour hiring in or selling out; *Kibanja* holding, and ownership of assets such as television and radio. In the HRZ, the largest proportion of households fell equally into RG3 and RG4 each comprising 33% of total households. In the LRZ, the largest proportion was RG3 (63%) whereas 10-14% of the farmers fell into each of other groups (RG1, RG2, and RG4).

In both rainfall zones, household size was smallest in RG4, which was reflected in having the least family farm labour (Table 15), and household size was an important discriminating variable between the resource groups. Access to and use of common recourses and the production constraints faced such as labour shortage, lack of manure, small size of farms, and low farm-based income differed strongly between the different resource groups. Labour sharing was a strategy of RG4 households in the HRZ, whereas in the LRZ labour sharing was prominent in RG3 and RG4. This is a strategy to address labour constraints among themselves since they cannot afford to hire labour. Selling out farm labour was noted in both RG3 and RG4 for both zones.

Table 14: Household categories based on wealth ranking (WR) making four resource groups (RG) provided by focused group of farmers[a]

Category	Butayaibega village (High rainfall zone) (724 households)	Butulage village (Low rainfall zone) (890 households)
A. Wealthy (RG1)	May own a car or motorcycle; a television; good modern house built by burnt bricks, cement, iron roof, have manured for their *Kibanja,* have dairy cows; may own tree plantation in the *rweya;* employ full time labourers in the farm; and are able to pay for higher education for their children (15%)	*Kibanja* area > 1.4 ha; have transport facility such as motorcycle; a radio; hire labourers to work in their *kibanja* ; have a good house with cemented floor, burnt bricks and /or painted; have cattle (13%).
B. Average (RG2)	*Kibanja* is clean, have moderate to good house built by mud bricks, iron roofed, the floor may be cemented; have radio, bicycle; may keep goats or local cow(s) or pigs; have a motorcycle; may hire some labourers especially during the season; can afford to pay for children's education up to secondary school level (19%)	*Kibanja* 1-1.35 ha; has average quality weedfree mulched *kibanja;* have a bicycle; keep about five goats; A house is roofed with corrugated iron sheets; can afford hiring farm labour during planting season (14%)
C. Poor (RG3)	Have *kibanja* though may be overwhelmed by weeds, often are food insecure, no transport facility; may own a radio (33%).	Have small *kibanja* (<1 ha), cannot maintain it well; Poor grass roofed house; no transport facility; may have few chicken (63%)
D. Very poor (RG4)	Poor grass roofed house, very poor managed *kibanja* with weeds; food insecure, their children may be enrolled in school, but often absconds from schools for waged labour to earn income for the household (33%).	Have very poor grass roofed house or homeless; sell labour to other farmers; food insecure; no land or very small; may keep few chicken (10%)

[a] Composition of households in each category in parentheses (as %) of total households in the village).

Table 15: Mean values for characteristics of households based on resource endowment status across four wealth categories in the high rainfall zone and low rainfall zone of Bukoba District[a]

Zone	Resource groups[1,2]	Land holding and use (ha)				Household socioeconomics					
						Labour supply (in person-days)[b]				Income ('000'shilings)	
		Kibanja[2]	*Kikamba**	*Rweya*	Woodlot[1]	Farmily	Hired[1,2]	Sold[1,2]	Shared*	Farm*	Off-farm*
HRZ	RG1	1.1 (0.20)	0.1 (0.03)	1.1 (0.5)	1.5 (0.8)	739 (95)	349 (52)	0	0	88 (23)	586 (94)
	RG2	0.7 (0.10)	0.1 (0.03)	0.4 (0.2)	0.4 (0.2)	628 (98)	59 (35)	9 (6)	0	47 (11)	163 (39)
	RG3	0.4 (0.10)	0.1 (0.01)	0.2 (0.1)	0.2 (0.1)	594 (48)	38 (21)	23 (8)	1 (1)	31 (12)	217 (65)
	RG4	0.2 (0.03)	0.1 (0.03)	0.1 (0.0)	0.1 (0.1)	481 (27)	0	9 (5)	8 (5)	35 (7)	82 (19)
LRZ	RG1	2.7 (0.30)	0.2 (0.1)	0.2 (0.1)	0.3 (0.1)	588 (79)	268 (75)	0	0	372 (64)	266 (59)
	RG2	1.8 (0.30)	0.2 (0.1)	0.6 (0.2)	0.3 (0.2)	664 (76)	73 (28)	9 (5)	0	422 (66)	212 (96)
	RG3	1.2 (0.10)	0.3 (0.1)	0.3 (0.1)	0.4 (0.2)	595 (39)	8 (3)	36 (5)	19 (7)	154 (17)	62 (12)
	RG4	0.8 (0.40)	0.2 (0.1)	0.1 (0.1)	0	491 (68)	0	120 (38)	41 (29)	98 (21)	42 (19)

[a]Data are based on 74 households in the HRZ and 77 households in the LRZ. Standard errors in parenthesis.

[1]Variable mentioned by key informants as wealth indicators in the HRZ;

[2]Variables mentioned in the LRZ

[*]Variables which were not explicitly mentioned by farmers but included in researchers variables list because were found to be important variables among households. The shared labour in this case does not include livestock herding among livestock keepers but includes labour shared among women guilds mainly for *omusiri* cultivation during the season

[b]PD = Person-day, equivalent to labour provided by one adult person with age between 18-59 years working for 8 hours a day. The equivalence for different age groups in years is calculated as: ≥ 60 (0.8); 14 - 17 (0.8); 5 - 13 (0.5), 1 - 4 (0.25). HRZ: High rainfall zone; LRZ: Low rainfall zone

Table 16: Mean values for household characteristics in terms of livestock ownership and the use of common property resources across four wealth categories in the high rainfall zone and low rainfall zone of Bukoba District[a]

Zone	Resource groups[1,2]	Livestock ownership and manure production[1,2]						Use of *Rweya* resources			
		Indiginous cattle	Improved cattle	Goats	Pigs	Chicken	Manure (kg month^{-1})	Mulch (t yr^{-1})[2]	Fodder (t yr^{-1})*	Bedding (t yr^{-1})*	Carpet (tyr^{-1})*
HRZ											
	RG1	3.9 (1.5)	0.3 (0.2)	1.5 (0.6)	0.9 (0.4)	1.9 (0.9)	504 (178)	15 (3.8)	7 (2.7)	0.4 (0.1)	0.2 (.04)
	RG2	1.8 (0.6)	0.2 (0.2)	0.4 (0.4)	0.9 (0.4)	2.4 (1.6)	166 (74)	5 (1.4)	5 (3)	0.2 (0.1)	0.3 (.05)
	RG3	0	0	1.2 (0.4)	0.5 (0.3)	2.7 (0.8)	23 (7)	2 (0.4)	3 (1.3)	0	0.3 (.02)
	RG4	0	0	0.5 (0.2)	0.1 (.04)	1.5 (0.5)	8 (3)	1 (0.2)	1 (0.3)	0	0.3 (.03)
LRZ											
	RG1	5.2 (2.2)	0.2 (0.2)	2.5 (0.9)	0.2 (0.1)	1.8 (1.1)	497 (138)	28 (8.6)	9 (3)	0.1 (0.1)	0.2 (.04)
	RG2	0.2 (0.2)	0	4.9 (0.9)	0	6.2 (1.9)	36 (5)	10 (1.8)	3 (0.9)	0.2 (0.1)	0.3 (.04)
	RG3	0	0	1.9 (0.4)	0.2 (0.1)	3.2 (0.5)	18 (4)	7 (1.1)	2 (0.6)	0.1(0)	0.3 (.02)
	RG4	0	0	0.3 (0.3)	0	1.1 (0.6)	4 (4)	5 (2.9)	1 (0.8)	0	0.3 (.03)

[a]Data are based on 74 households in the HRZ and 77 households in the HRZ. Standard errors in parenthesis

[1]Variable mentioned by key informants as wealth indicators in the HRZ;

[2]Variables mentioned in the LRZ

*Variable not explicitly mentioned by farmers but included in researchers variables list because they were found to be important variables among households.

Farmers in the HRZ were found to have more non-farm activities as reflected in off-farm income than in the LRZ (Table 15). This information is important in designing technologies for agricultural development. It means that farmers in the HRZ tend to operate as semi-urban settlers probably because of the vicinity of Bukoba town (approximately 14 km) compared with the LRZ where farmers are further away from the urban centre (80 km).

Despite the importance of cattle in the farming system, only 21% of the households owned cattle in the HRZ (n=74) and 16% in the LRZ (n=77). However, ownership of goats, pigs and chicken were found in all resource groups albeit with a decreasing trend from RG1 to RG4 (Table 16). Apparently, the use of mulch in the *Kibanja* per household was highly biased to RG1 households (wealthy) compared with RG4 households. The amount of mulch collected by households (in tons yr^{-1}) ranged from 1 (RG4) to 15 (RG1) in the HRZ and from 5 (RG4) to 28 (RG1) in the LRZ. Mulch collection from the *Rweya* is a labour demanding activity. In this system, we found that family labour is generally the most used for collecting mulch from the *Rweya*, and requires 80 – 100 person-days to cut 400 bundles which are considered sufficient to maintain 0.4 ha of *Kibanja* per year. These quantities applied are similar to the 20 tons of fresh mulch ha^{-1} to the *Kibanja* reported to be required to produce 15 tons ha^{-1} y^{-1} of bananas, and 0.225 tons ha^{-1} y^{-1} of hulled coffee Rald & Rald (1975). These production estimates apply for *Kibanja* with a 2:1 (banana: coffee) mixture and under common farmer management with only mulch and no manure input. The wealthier farmers employ extra labour for this activity or buy ready-cut mulch grass from the roadside which was often sold at around 300-400 Tanzanian shillings (0.25-

0.3 USD) per bundle during 2005-2007. One good bundle of mulch weighs 20-25 kg of fresh grass, which means that on average only one bundle at a time can be transported by one person from the *Rweya* to the farm.

The quantity of mulch cut directly from the *Rweya* was significantly larger for RG1 households, and further followed the order RG2>RG3>RG4 in both rainfall zones, suggesting that mulch application to the *Kibanja* is a strong driver of household variability in resource use. Manure and fodder use followed the same trend. However, grass that is used for household carpeting and later after expiration applied into the *Kibanja* as mulch had equal importance in all resource groups in both rainfall zones. More land was privately owned in the *Rweya*, whether planted with trees or not, by RG1 households with decreasing amounts towards the RG4 households in both agro ecological zones. The variation between the resources groups in the area of the *Rweya* privately owned was slightly less in the LRZ implying less land pressure.

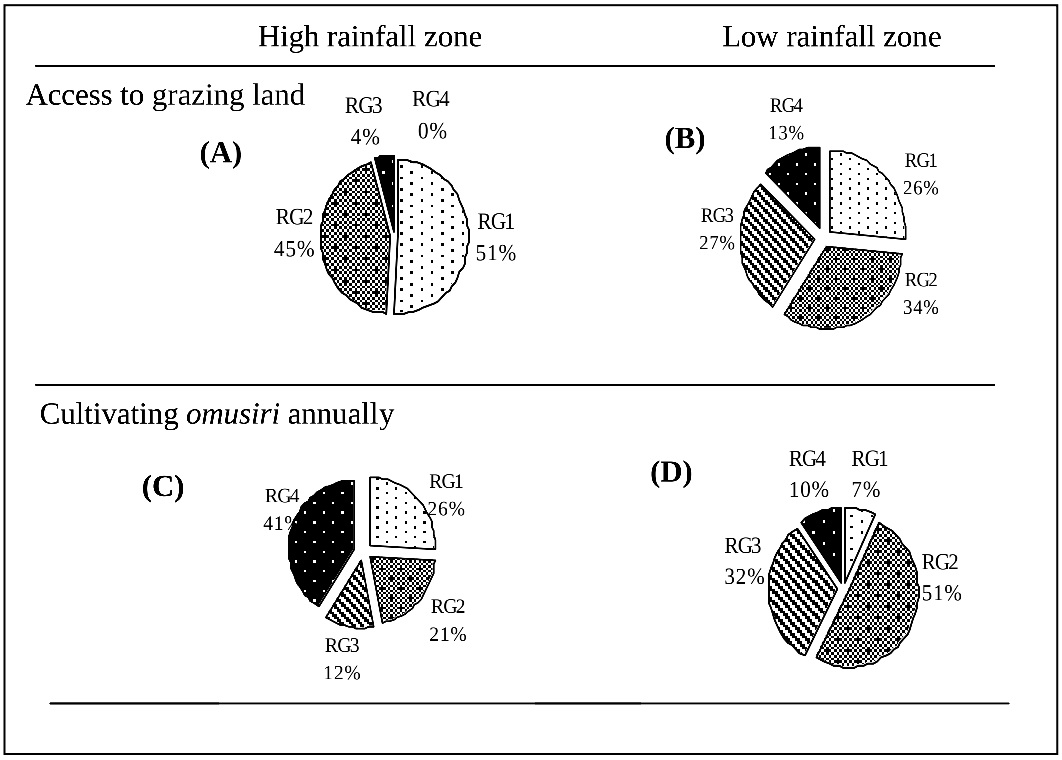


Figure 10: Proportions of households in % of resource group for: (A & B) having free grazing livestock on the Rweya for HRZ and LRZ respectively; (C & D) dependence on Omusiri for the household in the HRZ and LRZ respectively in 2005

In the HRZ, 51% and 45% of farmers in RG1 and RG2, respectively, had cattle that graze freely in the *Rweya* (Figure 10). However, in the LRZ there was no substantial difference between the proportions of households having free grazing livestock in the *Rweya* although RG4 had the least proportion (13%). Most households in the LRZ keep goats that are free grazers whereas in the HRZ most goats and dairy cattle are fed in the stables to maximize manure production for the *Kibanja.*

Regarding dependence on *Omusiri,* the largest proportion was in RG4 (41%) while RG3 had the least proportion (12%) with similar proportions in RG1 and RG2

(Figure 10C). In the LRZ (Figure 10D), RG2 and RG3 depended more on *Omusiri* (51% for RG2 and 32% for RG3) compared with RG1 (7%) and RG4 (10%). The reasons underlying lower dependency on *Omusiri* for RG1 and RG4 in the LRZ are distinct. While RG1 had a large *Kibanja* producing surplus bananas for sale, RG4 had only a small *Kibanja*, and spent more time selling labour to other households during the *Omusiri* cultivation season, which may explain why this group was considered to be food insecure during the wealth ranking process.

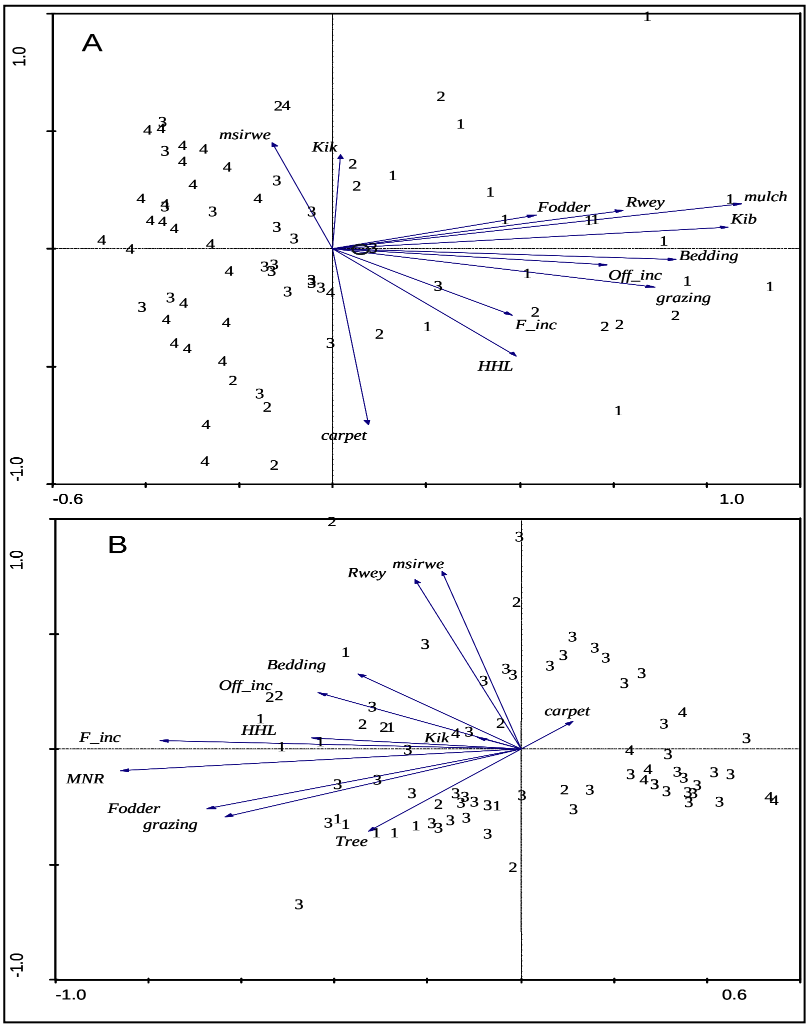


Figure 11: Ordination bi-plot diagram of household characterization based on PCA of log (variables) by researchers for (A) HRZ and (B) LRZ

Key: The numbers 1-4 on the plane indicate the four resource groups. Each arrow points in the direction of steepest increase of values for the corresponding variables. The angles between arrows indicate the sign of correlation between the variables; the approximate correlation is positive when the angle is sharp and negative when the angle is larger than 90 degrees. The length of arrow is a measure of fit of the variables. The lengths of the arrows are the multiple correlations of those variables with the ordination axis. The distance between the positions of the household approximates the dissimilarity of their variables measured by Euclidean distance. Samples close to the origin have average values of a particular variable in a study sample.

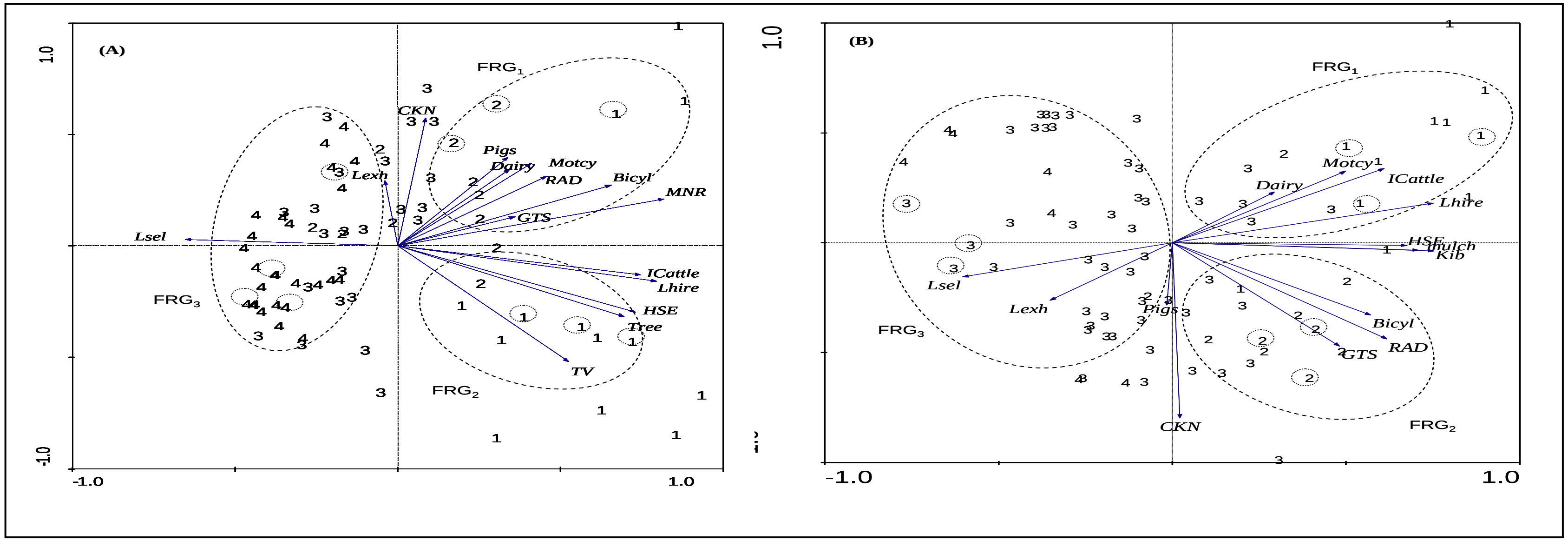


Figure 12: Ordination bi-plot diagram of household characterization based on PCA of log (variables) for farmer-derived variables (FDV) defining wealth

Key: (A) HRZ and (B) LRZ, respectively, represented by arrows. Each arrow points in the direction of steepest increase of values for the corresponding variables. The angle between arrows indicates the degree of correlation between the variables. The lengths of arrows are measures of fit of variables. The distance between the positions of the households represented by the wealth ranking score approximates to the dissimilarity of their variables measured by Euclidean distance. Samples close to the origin have average values of a particular variable in a study sample. The household selected for detailed characterization are indicated by small circles.

Despite land shortage being a critical constraint in the farming system and the inherent poor soil fertility status, the use of mineral fertilizer is not common due to two main reasons. First, fertilizers are too expensive for most households and secondly, fertilizers were perceived to worsen the quality of the already degraded soils. As a result, farmers maintained traditional ways of soil fertility management particularly using local organic resources such as crop residues, animal manure (for those with livestock) and mulches, which are also used to suppress weeds. These findings indicate that different resource groups highly vary in the quantity of organic resources applied in their *bibanja*, which was likely to be the major factor leading to different levels of farm productivity. Nevertheless, there are other factors that lead to this variability such as disrupted land tenure arrangements in the farming system and farm labour constraints. For example, (Mwijage *et al.*, 2011) observed that the youths in the HRZ were greatly concerned with the privatization of the formerly communally owned that were then annexed to individuals who plant trees to subsequently claim their ownership. This trend was eventually leading to limited areas for availability of mulch and grazing lands.

Defining functional resource groups using principal component analysis

Based on principal component analysis, the importance of each variable in explaining the variability among households was assessed. Four principal components (PCs) were generated based on variables (Table 15) identified by researchers (Figure 11) and farmers (Figure 12). The four principal components explained 67% and 56% of total variance for researcher-identified variables in the HRZ and LRZ, respectively; and 60% and 59% for farmers' variables in HRZ and

LRZ, respectively (Table 17). The loadings of variables on the four principal components are summarized in Figure 10**.** All variables had both high positive or negative loadings in at least one of the four principal components.

Based on researchers' variables, the first two axes explained 47% (HRZ) and 35% (LRZ) of household variability. Using farmers' variables, the first two principal components explained 41% (HRZ) and 42% (LRZ) of the variance (Table 17). Due to the fact that the variance explained by the two principal components was small, (i.e. between 35% - 47%), and the large variance between households (Figures 11 and 12), cluster analysis to generate farm typologies was not done. As we wanted to follow the wealth ranking as perceived by farmers as closely as possible, we decided to take the PCA that used farmers' variables as the basis for selection of farms for detailed investigation (Figure 12).

Table 17: Eigenvalues and % of variance explained by variables in four principal components in the HRZ and LRZ

Zone	PC axis	Researchers' variables		Farmer-derived variables	
		Eigenvalues	Cumulative variance%	Eigenvalues	Cumulative variance%
HRZ	1	0.34	34	0.30	30
	2	0.13	47	0.11	41
	3	0.12	59	0.10	51
	4	0.08	**67**	0.08	**60**
LRZ	1	0.22	22	0.30	30
	2	0.13	35	0.12	42
	3	0.11	46	0.09	50
	4	0.10	**56**	0.08	**59**

Farms that were close to the *X* or *Y*-axis were not considered during household grouping. In general, in the HRZ (Figure 12A), most households in the right hand upper quadrant were designated as RG2 during the wealth ranking process. Households in the right hand lower quadrant were ranked into RG1. Households ranked in RG3 and RG4 were scattered over the left hand quadrants. These households differ from those at the right hand quadrants by selling of labour (*Lsel*) and weakly by labour exchange (*Lexh*); we decided to take households in the left hand half as one group of households. A similar picture arose for the LRZ (Figure 12B) with the exception that households situated in the right hand upper corner were now mainly the households that were ranked as RG1 during the wealth ranking process and those in the right hand lower corner as RG2. We considered the households in the right hand upper and lower corners each as one functional resource group (FRG_1 and FRG_2). The households in the left half were considered as one resource group (FRG_3).

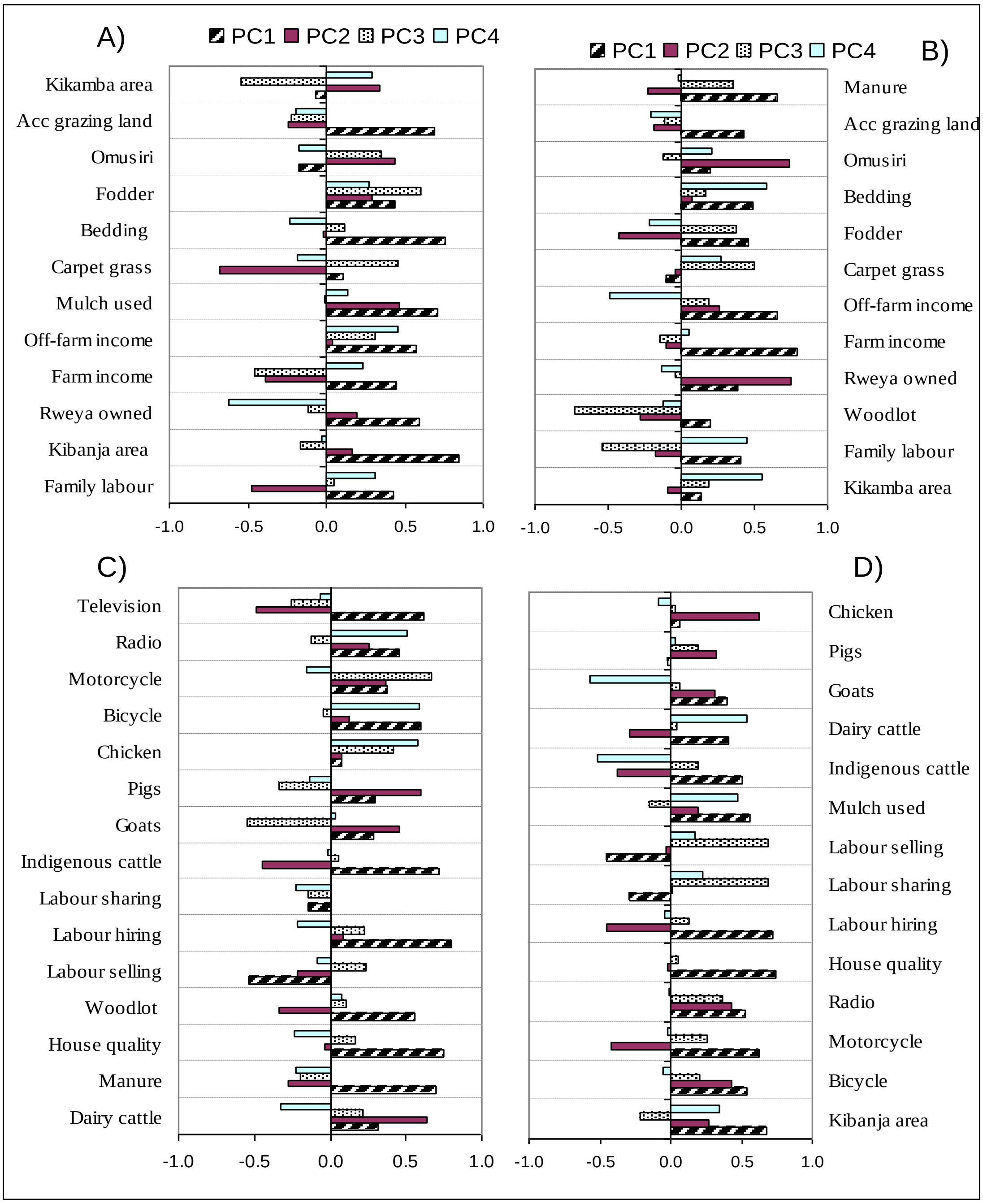


Figure 13: The loadings of different variables with respect to the four main principal components

Key: A & B researchers' variables for high (A) and low rainfall (B) zone, respectively, and C & D for farmers' variables in the high (C) and low rainfall (D) zone, respectively.

In the HRZ (Figure 12A), FRG_1 and FRG_2 had similar characteristics in the sense that both had livestock and their distinguishing defining variables were positively correlated. However, households in FRG_1 were more specialized in dairy cattle managed under stall feeding (*Dairy*) while those in FRG_2 were more specialized in free grazing indigenous cattle (*Lcattle*). Variables related to agricultural production namely the dairy cattle (*Dairy*), goats (*GTS*), pigs and manure collected (*MNR*) were all highly correlated to each other (right hand upper corner) and defined FRG_1. Owning local cattle, labour hiring and acreage of planted trees on the *Rweya* were all highly related to each other (right hand lower corner) and defined FRG_2.

The households in FRG_3 were characterised by high association with selling out (*Lsel*) and sharing agricultural labour (*Lexh*). The amount of manure collected (*MNR*) and labour sold out (*Lsel*) had longer arrows indicating they are more important in defining household characteristics than labour exchange (*Lexh*) which had a shorter arrow. In the HRZ, 8% of households were intermediate between FRG_1 and FRG_3 (5 households) and one household between FRG_1 and FRG_2, and two households between FRG_2 and FRG_3. The three main functional resource groups of households in the HRZ were defined by: FRG_1 (dairy cows, pigs and goats managed under zero grazing system); FRG_2 (local cattle, tree plantation, and labour hiring); FRG_3 (selling and exchanging labour, and in shortage of all other variables as displayed on the PCA plane (Figure 12A)). Labour hiring was important in separating in $FRG_{2,}$ and FRG_1 from FRG_3, being negatively associated with selling and exchanging labour.

In the LRZ, labour hiring (*Lhire*) and cattle ownership (*Icattle*) were highly positively related and defined FRG_1. Keeping goats (*GTS*) was highly associated with FRG_2. *Kibanja* sizes (*Kib*) and mulch collection (*mulch*) were shared with FRG_1. Ownership of assets such as bicycles (*Bicyl*) and radios (*RAD*) defined FRG_2. Labour selling out (*Lsel*) and labour exchange (*Lexh*) by household members were highly associated with FRG_3 as in the HRZ. In the LRZ, 5% of households located close to the origin of the axis, and could not be placed on one of the categories.

Households selected for the detailed characterisation are circled in Figure 12. As can be seen, households not close to the *X* or *Y*-axis were selected to obtain clear differences between the functional resource groups. Table 18 summarizes the characteristics of the selected farms per three functional resource groups for the HRZ and LRZ. These characteristics are averages calculated based on the data collected in the rapid survey containing both researchers' and farmers' variables. FRG_3 represents the largest portion of households in both zones, whilst FRG_1 and FGR_2 represent both a smaller but equal portion of the total population. Generally FRG_3 did not own livestock particularly ruminants, but had few chicken and pigs. Household size was smallest in FRG_3. The status of resource endowments for the household influenced the variability between their farms and was related to constraints to production. The largest group (FRG_3) was faced with multiple constraints including small land area, lack of manure, labour constraints, and they competed for resources such as mulch from the communal land.

Table 18: General characteristics of functional farm types

	Family size	Labour (person-days/year)*				Land holding (ha)			Number of livestock				Farm inputs		Farm income (US$ yr^{-1})	Main crops[2]	
		Family	Hired	Sold	Shared	*Kibanja*	*Kikamba*	*Rweya*	Cattle	Goats	Pigs	Chicken	Manure DM Mg yr^{-1}	Mulch Mg yr^{-1}		Food	Cash
High rainfall zone [3]																	
FRG_1 (n=3)	6.7	520	364	0	0	0.8	0.2	0.6	1.7	0.7	0.7	0	8.4	9.1	540	ba, be, mz, sp	co, tr, va
FRG_2 (n=3)	9.3	760	176	0	0	0.6	0.2	0.6	2.7	2	0.3	0	2.5	6.2	348	ba, be, mz, pi, ya, pa, cv, sp	co
FRG_3 (n=4)	4.5	520	0	32	0	0.4	0.04	0.01	0	0	0.3	1.5	0	0.2	72	ba, be, cv, mz,sp	co, pa
Low rainfall zone [4]																	
FRG_1 (n=3)	8.0	702	41	0	0	1.6	0.2	0.3	2	1.5	0	0	0.7	7.3	878	ba, be, mz, cv, py, av	co, tr
FRG_2 (n=3)	6.5	520	15	0	22	3.0	0.1	0.2	0	3	0	0	0.6	10.9	526	ba, be, cv, mz, sp, av,	co, tr, pa
FRG_3 (n=3)	6.3	607	0	27	47	0.4	0.1	0.0	0	0	0	0	0	0.8	167	ba, be, cv, mz, sp, gn	co

[2]ba = bananas; be = beans; mz = maize; cv = cassava; sp = sweet potato; av = avocado; ya = yams; pi = pineapple; gn = groundnuts; co = coffee; va = vanilla; tr = trees; pa = pasture

[3]Average distance from the nearest town is 14 km; annual rainfall 2100 mm; Location: 01º26' - 01º27' S; 031º47' E

[4]Average distance from the nearest town is 80 km; Average annual rainfall 750 mm; Location: 01º27' - 01º30' S; 031º29' - 031º30' E

*PD = Person-day, equivalent to labour provided by one adult person with age between 18-59 years working for 8 hours a day. The equivalence for different age groups in years is calculated as: ≥ 60 (0.8); 14 - 17 (0.8); 5 - 13 (0.5), 1 - 4 (0.25). HRZ: High rainfall zone; LRZ: Low rainfall zone

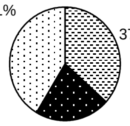
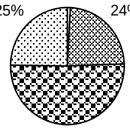
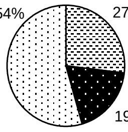
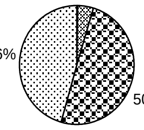
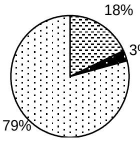
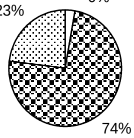
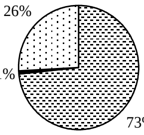
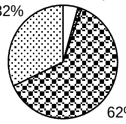
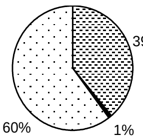
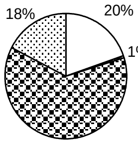
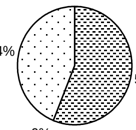
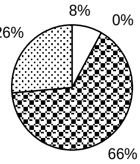
Detailed characterization of functional resource groups

Farm income and expenditure sources

Large differences were observed between source of incomes, both from agricultural based enterprises and off-farm sources across the zones and functional resource groups within zones (Figure 12). The large contribution of livestock based income in the HRZ especially in FRG_1 and FRG_2 demonstrates that the livestock component in the system is important for further system intensification especially with regard to current increasing land pressures. By improving the feeding system with high quality forages and purchased supplementary feeds, manure and milk production can be enhanced. This is particularly in the HRZ, where there are better marketing opportunities of dairy products due to closeness of urban market in Bukoba town, thus capturing relatively higher prices for livestock products. In contrast, the high farm income from crop sales for FRG_1 and FRG_3 in the LRZ is due to sales during the peak seasons of June to August of bananas, and beans (from January to March). Substantial farm-based income in the LRZ was observed to come from sales of food crops rather than from coffee, the traditional cash crop. High expenditure on livestock enterprises in FRG_1 (HRZ) was due to the need for hiring full time labourers to cut and carry fodder in stall-feeding systems. The expenditure on livestock enterprises in FRG_2 is smaller in relation to the respective income; this is explained by the labour sharing mechanism among cattle owning households where labour is provided on a rotation basis among the owners of free grazing cattle that limits direct expense in terms of cash on livestock management.

Food security

Food security is key criterion in assessing the efficiency and state of farming systems. Differences were observed in the contribution of different types of commodities to food security in the families within and across the zones (Figure 17). Livestock products produced in the farm contributed to the family energy and protein needs in FRG_1 and FRG_2 in the HRZ, but contributed virtually nothing to FRG_3 in the HRZ, or all groups in the LRZ. The purchased products, usually fish, sugar, rice, beef, cooking oil, maize meal, wheat flour for making unleavened breads (*chapatti)* and buns *(maandazi)*, were the main contributors of energy and protein requirements in FRG_2 for the LRZ. Beans often play major roles in monthly energy and protein intake in FRG_3 in the HRZ and all groups in the LRZ. In the HRZ, energy and protein requirements were never met with a deficit ranging from 36% to 52% for energy, and 19% to 40% deficit in protein. However, in the LRZ the energy deficit ranged from 21% to 47% but only protein was deficient in FRG_3. This result can be used as proxy indicator for food insecurity in the system, and external food dependency. Common bean (*Phaseolus vulgaris*) was the major source of daily dietary protein needs in the system. Protein deficit in FRG_3 in the LRZ may be attributed to overselling of farm harvests during the season. However, poor production of beans in the HRZ, explains the observed deficit in protein intake for all farm types.

	Income from agricultural enterprises	Annual expenditure sources	Gross annual income (USD)			Annual expenses (USD)			
			Products with highest contribution to household income*	Agricultural enterprises	Off-farm	Cropping costs	Livestock keeping	Food for household	Other expenses
(A) HRZ									
FRG$_1$ (n=3)			mk va, ba	596	420	8.4	204	439	214
FRG$_2$ (n=3)			co, tr, ba mk	551	648	2.5	36	412	379
FRG$_3$ (n=4)			co, pa ba	79	300	10.8	0	295	92
(B) LRZ FRG$_1$ (n=3)			be, ba, co mz, cv, gt	878	306	30	7	407	207
FRG$_2$ (n=3)			be, ba, cv co, mz, gt	526	800	191	5	602	171
FRG$_3$ (n=3)			be, ba, cv co, sp	167	132	22	0	180	72

Crop products · Off-farm income · Cropping costs · Food for household

Livestock products · Livestock keeping · Others

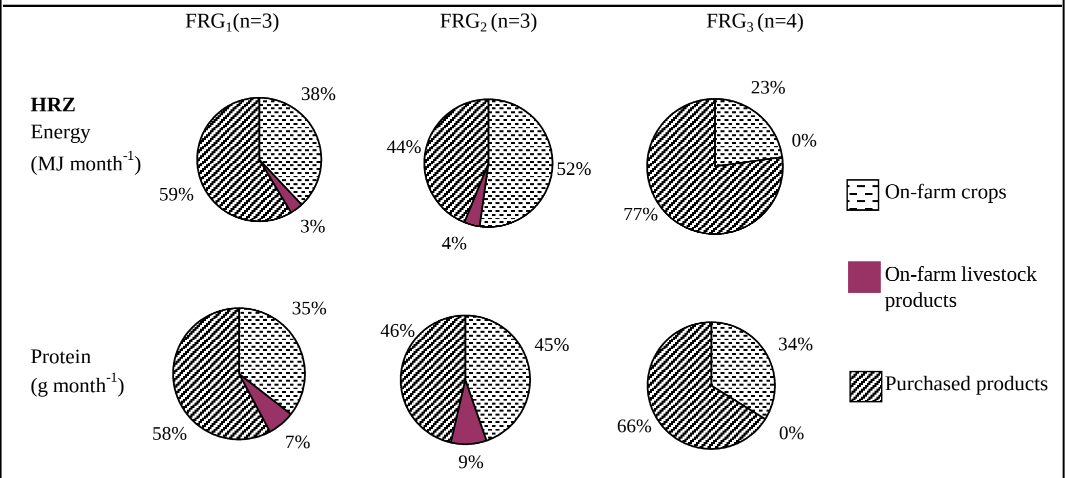
Key: *ba = bananas; be = beans; mz = maize; cv = cassava; sp = sweet potato; av = avocado; ya = yams; pi = pineapple; gn = groundnuts; co = coffee; va = vanilla; tr = trees; pa = pasture; mk = milk.

Figure 14: Distribution of average main sources of annual income and expenditure in case study farms at HRZ and LRZ in Bukoba over two years

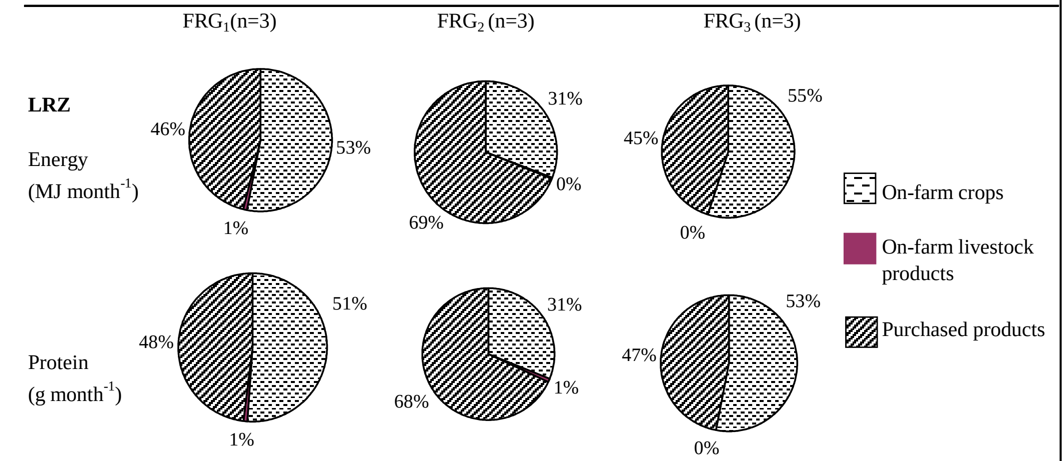
Despite having livestock, protein intake in FRG_1 and FRG_2 was surprisingly low in both zones. This could be associated with limited productivity of livestock kept that is associated with inadequate nutritional and health management of the animals as well as the fact that some of the little products such as milk and eggs are sold for cash. On the other hand, the productive uses of livestock at household levels were mainly manure generation and milk for household consumption.

Farm nutrient balances

The nutrient balances for N, P, and K in the *Kibanja* in the HRZ were generally positive in FRG_1 and FRG_2. FRG_3 had negative nutrient balances. However, for all functional resource groups the soil nutrient balances were negative for the *Kikamba* plots in both rainfall zones (Table 19). This can be explained by the fact that *Kikamba* plots were located farthest from the homesteads showing that farmers tend to concentrate nutrient inputs to the *Kibanja* at the expenses of *Rweya* and *Kikamba*. This pattern is also observed elsewhere in other African farming systems of Western Kenya and Zimbabwe where smallholder farmers tend to concentrate nutrient inputs near the homesteads (Tittonell *et al*., 2007; Zingore *et al*., 2007b). In Bukoba District, the nutrient balances are driven by livestock ownership and heavy use of mulch (Table 19).



	FRG1 (n=3)	FRG2 (n=3)	FRG3 (n=4)
Energy requirements met	No (46% deficit)	No (52% deficit)	No (36% deficit)
Protein requirements met	No (19% deficit)	No (40% deficit)	No (21% deficit)
On-farm products contributing to family nutrition[1]	ba, sp, milk	ba, ya, sp, milk	cv, sp, ba, be



	FRG1 (n=3)	FRG2 (n=3)	FRG3 (n=3)
Energy requirements met	No (21% deficit)	No (32% deficit)	No (47% deficit)
Protein requirements met	Yes	Yes	No (23% deficit)
On-farm products contributing to family nutrition[1]	ba, be, mz	ba, be, mz, sp	ba, be, mz, sp

Figure 15: Distribution of sources of annual food security in the case study farms at HRZ and LRZ, Bukoba District, 2005-2007

Table 19: Annual organic inputs for N, P, and K ($Kgha^{-1}yr^{-1}$) through manure and mulch, and removed through consumption, sales, and stored; and partial balances for the different farm resource group types for *Kibanja* and *Kikamba* in the HRZ and LRZ

		High rainfall zone*								Low rainfall zone[§]							
	FRG	From on farm	From off farm	Total inputs	Household consumption	For Sale	Store	Total outputs	Balance (kg ha^{-1})	From on farm	From off farm	Total inputs	Household consumption	For Sale	Store	Total outputs	Balance (kg ha^{-1})
Kibanja																	
N	FRG_1	47	0	47	8	9	0	17	**31**	1.7	1	2	3	3	0	6	**-3**
	FRG_2	37	4	41	12	1	0	13	**28**	2.6	1	3	4	15	1	20	**-17**
	FRG_3	0	0	0	10	0	0	11	**-11**	0.0	0	0	13	7	0	20	**-20**
P	FRG_1	15	0	15	1	1	0	2	**12**	0.4	0	0	0	0	0	1	**0**
	FRG_2	11	2	12	2	0	0	2	**10**	0.6	0	1	1	2	0	3	**-2**
	FRG_3	0	0	0	1	0	0	2	**-2**	0.0	0	0	2	1	0	3	**-3**
K	FRG_1	58	0	58	3	3	0	6	**52**	1.9	0	2	1	1	0	2	**0**
	FRG_2	50	3	53	6	0	0	7	**46**	2.6	0	3	2	2	0	9	**-6**
	FRG_3	0	0	0	6	1	0	7	**-7**	0.0	0	0	6	3	0	9	**-9**
Kikamba																	
N	FRG_1	0	0	0	3	1	0	4	**-4**	0	0	0	10	19	0	28	**-28**
	FRG_2	0	0	0	6	6	0	12	**-12**	0	0	0	1	0	0	1	**-1**
	FRG_3	0	0	0	8	0	0	8	**-8**	0	0	0	2	1	0	3	**-3**
P	FRG_1	0	0	0	1	0	0	1	**-1**	0	0	0	1	3	0	4	**-4**
	FRG_2	0	0	0	1	1	0	2	**-2**	0	0	0	0	0	0	0	**0**
	FRG_3	0	0	0	2	0	0	2	**-2**	0	0	0	0	0	0	1	**-1**
K	FRG_1	0	0	0	4	2	0	5	**-5**	0	0	0	4	7	0	11	**-11**
	FRG_2	0	0	0	2	1	0	3	**-3**	0	0	0	1	0	0	2	**-2**
	FRG_3	0	0	0	13	0	0	13	**-13**	0	0	0	3	2	0	4	**-4**

*Number of households for which the data are based: n=3 for FRG_1; n= 3 for FRG_2; n=4 for FRG_3

[§]Number of households on which the data are based for all FRGs, n=3.

The positive nutrient balance *of Kibanja* in the HRZ for FRG_1 and FRG_2 compared with LRZ is probably due to the small farm size where a large amount of organic resources is concentrated in a small area. However, the results indicate further that FRG_3 which do not have cattle (and thus have only manure available from goats, chicken and pigs) had more negative nutrient balances compared with those with cattle. These results suggest that livestock intensification could address the problem of declining soil fertility in the Bukoban agro-ecosystem. However, the *Rweya* (grasslands) have been subjected to continuous exploitation for centuries (Evans and Mitchell, 1961) in favour of the *Kibanja* through supplying the required livestock feed and organic inputs, and thus the inherently poor and exhausted soils in the *Rweya*.

The most negative balances for N, P, and K that occurred in the LRZ in both *Kibanja* and *Kikamba* was probably due to large output in harvest and relatively larger plot sizes where little or no manure and mulch were spread. These results indicate that soil nutrient stocks are declining even in fields that receive large amounts of organic inputs. However, full annual nutrient balances are likely to be worse because other processes were not taken into account during the calculations done in the present study. Factors such as biological nitrogen fixation, sedimentation, atmospheric deposition, leaching, gaseous losses, and erosion are also important in soil nutrient balances. The inflow and outflows of these processes are calculated using transfer functions but are not considered in the balances presented here because of uncertainty in quantifying these processes (Færge and Magid, 2004).

4.3 *Rweya* productivity

Soil characteristics for the *Rweya*

Table 20: Physical-chemical properties of soils from different depths at the experimental site

Depth range (cm)	00 - 20		50-75	
Annual rainfall range (mm)	Nkenge (900-1500)	Maruku (1500-2200)	Nkenge (900-1500)	Maruku (1500-2200)
Parent material*	SS	SS	SS	SS
Texture*	L	SL	SCL	SL-SCL
pH H_20	5	4.8	5.3	4.6
C (%)	1.2	2.3	0.6	13
C:N	15	21	Nd	Nd
av.P mg kg^{-1}	6	>28	5	21
Ca cmol kg^{-1}	1.6	0.1	1	0.1
Mg cmol kg^{-1}	0.9	0.1	0.7	0.1
K cmol kg^{-1}	0.21	0.08	0.2	0.12
B.Sat (%)	52	6	28	8
Al.Sat (%)	28	40	47	83
Ca:Mg	1.8	1	1.4	1

* SS= sandstone; SCL= Sandy Clay Loam; L=Loam; SL=Sandy Loam; Nd= Not determined

Soil characteristics at experimental sites were within, but towards the higher end, of ranges reported earlier (Table 20). The soil was poor in terms of soil organic matter content, and contained small concentrations of exchangeable bases, particularly calcium and potassium. Total annual rainfall during the study period was 1473 mm for Maruku station that was far less to the long-term mean of 2100 mm (40 years) and was well distributed during both the short rains from August to January and the long rains from April to June (Figure 17A).

Local Knowledge on Rweya uses and Management

During focus group discussions, farmers listed grass species and their preferred uses at various vegetative stages of growth (Tables 21&22). *Rweya* grasses were used by livestock keepers in both free grazing and by stall-feeding (cut and carry) systems. Among species identified in the field as suitable for free grazing by livestock, four species were reported to be mostly harvested for stall feeding; among which *Eragrostis mildbraedii* was mentioned as the mainly preferred. Farmers indicated that they burn the *Rweya* extensively during the dry season repeatedly between July and September due to poor quality for presumed mature grasses for grazing. Lesser areas are burnt during the short dry period from January to February. Most fires are often set by livestock keepers aiming to promote fresh re-growth of meadow for their cattle and to control ticks.

Hyparrhenia species, that are harvested when are mature (> 6 months after burning), was mentioned as favorite for direct application as mulch in the *Kibanja* due to their bulkiness thus providing effective ground cover. *E. olivacea* was reported to be applied as mulch in crop fields after being used for home carpeting for 4-6 months, whereas *H. dissoluta* mainly serve as mulch after being used to squeeze banana juice. The process start by chopping the grasses to shorter pieces (about 20-30cm) and mixed with ripened bananas, squeezed for some time to discharge banana juice that eventually is fermented to make local banana beer. *L. kagerensis* is used for thatching, normally harvested from April until June when it is considered to be sufficiently mature. Other minor uses of little significance for the *Rweya* include collection of fuel wood and wild fruit from scattered shrubs, collection of medicinal herbs and hunting of small wild animals.

Table 21: Farmers perception on common grass species in the *Rweya* by their names (local, common, and scientific), their uses as preferred by farmers identified during the PRA at Butairuka village (Maruku - High Rainfall Zone (n=18)) in Bukoba District

Local name	Common name	Scientific name	Uses[1]						Determinant quality characteristics
			< 6 months after burning		> 6 months after burning				
			FG	CCF	MG	CG	TG	BG	
Ekinshwi	Love grass	Eragrostis olivacea	XXX	-	XX	XXX	-	XX	biomass, maturity, dry
Omushanje	Thatching grass	*Hyparrhenia spp*	XXX	XX	XXX	-	X	XXX	durability, maturity, dry, biomass
Enkeke	Couchgrass	*Eragrostis mildbraedii*	XXX	XXX	-	-	-	-	tenderness, maturity
Eyojwe	Russetgrass	*Loudetia kagerensis*	XXX	-	XX	-	XXX	X	durability, maturity, dry
Eunda	Yellow thatching grass	*Hyperthelia dissoluta*	XXX	-	X	-	-	-	nutrition
Olumbugu	Couchgrass	*Digitaria scalarum*	XXX	XX	-	-	-	-	nutrition
Eshoju	Red oat grass	*Themeda triandra*	XX	XX	XXX	-	X	XX	nutrition , durability, maturity, biomass

[1] XXX most preferred, XX moderately, X rarely used, - never used; FG: Free grazing; CCF: Cut & carry forage; MG: Mulch grass; CG: Carpet grass; TG: Thatching grass; BP: Banana processing

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Table 22: Farmers perception on common grass species in the *Rweya* by their names (local, common, and scientific), their uses as preferred by farmers identified during the PRA at Nkenge village (Low Rainfall Zone (n=22)) in Bukoba District

Local	Common	Scientific	Uses[1] < 6 months after burning		> 6 months after burning				Determinant quality characteristics
			FG	CCF	MG	CG	TG	BP	
Ekinshwi	Love grass	*Eragrostis olivacea*	XXX	-	XX	XXX	-	XX	biomass, maturity, dry
Omushanje	Thatch grass	*Hyparrhenia spp*	XXX	XX	XXX	-	X	XXX	durability, maturity, dry
Enkeke	Couchgrass	*Eragrostis mildbraedii*	XXX	XX	-	-	-	-	tenderness, maturity
Etete	?	*Cymbopogon nardus*	XXX	-	XX	-	-	-	nutritional quality, green
Olumbugu	Couchgrass	*Digitaria scalarum*	XX	X	-	-	-	-	biomass, maturity, dry
Mwonyu	?	*Miscanthus violaceus*	XX	X	-	-	-	-	biomass, maturity, dry
Sindaga	?	*Hyperrhenia spp.*	XX	X	-	-	X	X	biomass, maturity, dry
Eshoju	Red ear grass	*Imperata cylindrica*	XX	X	XXX	XX	XX	XXX	nutrition , durability, maturity, biomass

[1] XXX most preferred, XX moderately, X rarely used, - never used; FG: Free grazing; CCF: Cut & carry forage; MG: Mulch grass; CG: Carpet grass; TG: Thatching grass; BP: Banana processing

Uses of *Rweya* Grasses

Plate 5: Picture showing different general uses of common *Rweya* grasses

Key: Thatched hut (A); Bundles of carpet grass on sale at roadsides (B); Cattle grazing in the *Rweya* (C); and Mulch for sale at roadside and mulched new *Kibanja* (D) in Bukoba District.

Grasses in tropical grasslands are directly grazed all year-round, and it is estimated that on average 30% of the biomass on offer can be consumed (de Ridder and Breman, 1993). In Bukoba, besides direct communal grazing by indigenous cattle (zebu) and goats, the *Rweya* grasses are also harvested as cut and carry fodder (for improved dairy cattle). Indigenous cattle graze freely in the *Rweya* during the day and are kept in bomas at night. It is estimated that approximately 40% of the manure is collected in the boma (Rufino *et al.*, 2006). By contrast, all of the manure is captured from the stall-fed animals. Manure is used exclusively within the *Kibanja* to maintain soil fertility and is rarely used on annual crops in the *Kikamba.* Manure is never in the shifting cultivation *Omusiri* plots.

A further major use of the *Rweya* is by cutting of mature grasses which are used as mulch in the *Kibanja,* a traditional farm management practice (Reining, 1967). Some grasses are first used for thatching, to produce carpets for use in the huts, or for brewing and are then transferred to the *Kibanja* for mulch (Plate 5). Farmers indicated that they favour mulching because it suppresses weeds, conserves soil moisture for the shallow rooting banana crop and maintains soil fertility. Pereira and Jones, (1954) reported mulching to be more effective than animal manure due to its multiple benefits. It is estimated that farmers commonly use 10 to 20 Mg ha^{-1} of mulch for establishing one acre of *Kibanja* on poor *Rweya* soils, followed by continuous use of 900 bundles (approximately 10 Mg) every six months to maintain the *Kibanja* (Rald and Rald, 1975). Thus there is a massive demand for mulch that also involves substantial labour investment. A good large bundle of grass for mulching weighs 20-25 kg and is normally harvested from the *Rweya* by family or hired labour. A substantial proportion of local people rely on selling the grass from the common *Rweya* at the roadside in bundles for mulch – a single bundle fetched about 400 Shillings (US$ 0.3-0.4) in 2006 (Figure 16). Given that the *Rweya* covers about 25% (~2020 ha) of the land in the Kyamutwara division (Baijukya *et al.*, 2005), and thus with an estimated biomass production of 7.4 Mg ha^{-1} in one year in the HRZ for example, cannot be meet all of the requirements of farming households. Competition for grass as mulch is therefore likely to increase considering the continued decrease of area under *Rweya* resulting from changes in land use for forestry. Besides *Rweya* grass, mulch for the *Kibanja* also comes from pruned banana leaves, crop residues from annual cropping fields, banana peels and homestead wastes which are usually returned to the banana plantation, although *Rweya* remains the main source of organic matter to sustain *Kibanja* productivity.

Measurements of *Rweya* Productivity

All grasses resprouted with the first rains after burning. In most cases, flowering started between January and March (within 4 to 6 months after burning). A thick layer of stemmy grass had developed when the long rains came in April to May. At the start of the short rains in August young shoots penetrated the dense layer. The standing biomass increased to March and then declined during the wettest period of the year before recovering again into the dry season (Figure 17B). Five grass species dominated the *Rweya* in the HRZ and contributed most of the total annual above ground biomass (Figure 17C, Table 17b). The relative contribution of *Elagrostis olivacea* decreased during the year, whereas that of *Hyparrhenia* spp. (a mixture of *H. rufa* and *H. hirta*) increased. The relative abundance of *Eragrostis mildbraedii, Loudetia kagerensis, Hyperthelia dissoluta,* remained relatively constant throughout the year except for *E. mildbraedii* whose contribution to total biomass increased rapidly between May to June (Figure 157). Although *E. olivacea* was relatively an abundant species, its contribution to total available standing biomass decreased with time, while that of *Hyparrhenia* spp increased significantly ($P<0.001$) at 6 month after burning (Figure 17C). Likewise, biomass of *E. mildbraedii* and *L. kagerensis* increased in May through June (i.e. 8 to 9 months after burning). Due to difficulties in distinguishing them, and their minor contribution to overall biomass, species such as *Digitaria scaralum* and *Themeda triandra* were grouped under 'others'.

At Nkenge site in (LRZ) six main grass species dominated in biomass productivity whereby *Hyparrhenia* spp, *Eragrostis* spp and *Imperata cylindrical* took the lead in dominance (Figure 17). However, variations in the contribution of individual specie to total biomass over time were somewhat constant in the LRZ throughout the measuring year.

Biomass productivity

The grass biomass from the *Rweya* for use in crop fields varied considerably during the year with peak values of about seven tons DM ha^{-1} during the last sampling month of July (i.e. 12 months after burning) (Table 4.4.2b). Although biomass productivity varied among main grass species, the contribution of *E. olivacea* to total available biomass decreased over time while the contribution of *Hyparrhenia* species increased. However, the amount of biomass available was maximal at around 5 Mg of DM ha^{-1} for the first six months for which the quality of the material was ideal for forage. From the bimonthly re-growth, however, the available biomass varied from 910 kg DM ha^{-1} to 2341 kg DM ha^{-1} with mean value of 1577 kg DM ha^{-1} (Table 25).

Despite well-distributed rainfall during the long rains season from April 2006, the amount of standing biomass decreased (Figure 17B), similar to the trend observed by Tueller and Tower, 1979, who described this phenomenon as ‘vegetation stagnation’. Since the experimental area was fenced, this decrease in biomass cannot have been caused by grazing or cutting. The exclusion of grazing animals, however, may have caused the smothering of shoots by accumulated dead material (McNaughton, 1979). In the absence of grazers, much of the standing dead material is broken down by wind and rain to form litter. Decomposition of litter material will have rapid during the rains. The standing biomass was largest at the end of the short rains season in September, 2006 dominated by *E. olivacea* for six months after burning after which the *Hyparrhenia* species took over (Figure 16C).

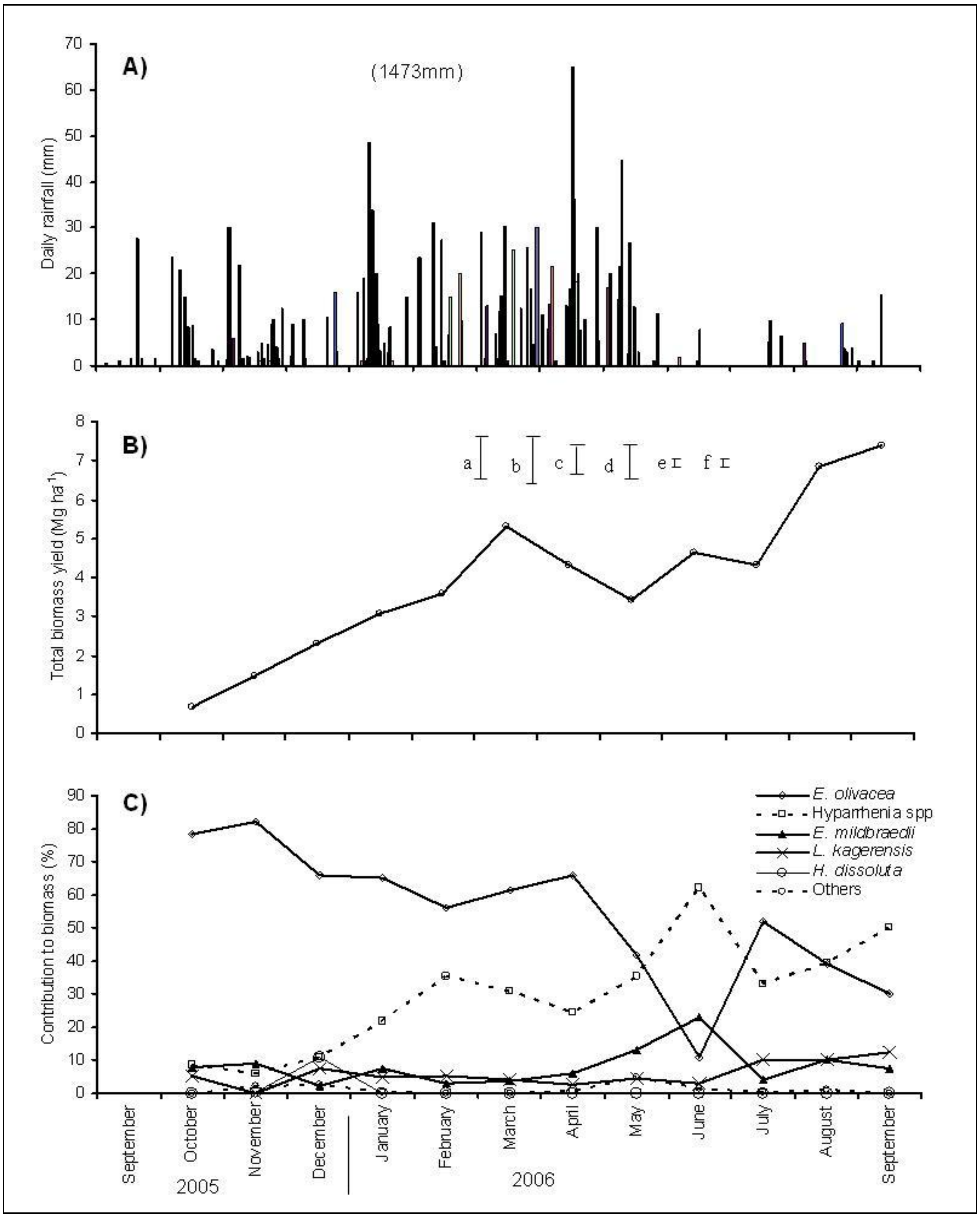

Figure 16: Daily precipitation (mm) (A); Total available standing biomass of grass (DM Mg ha-1 month-1) (B); and Relative contribution of dominant grass species over time to the total standing biomass in the Rweya as observed at Maruku experimental site (C) Key: Bars shows SEDs for means of different grass species: (a) *E. olivacea*; (b) *Hyparrhenia* spp; (c) *E. mildbraedii*; (d) *L. kagerensis*; (e) *H. dissoluta*; (f) Others.

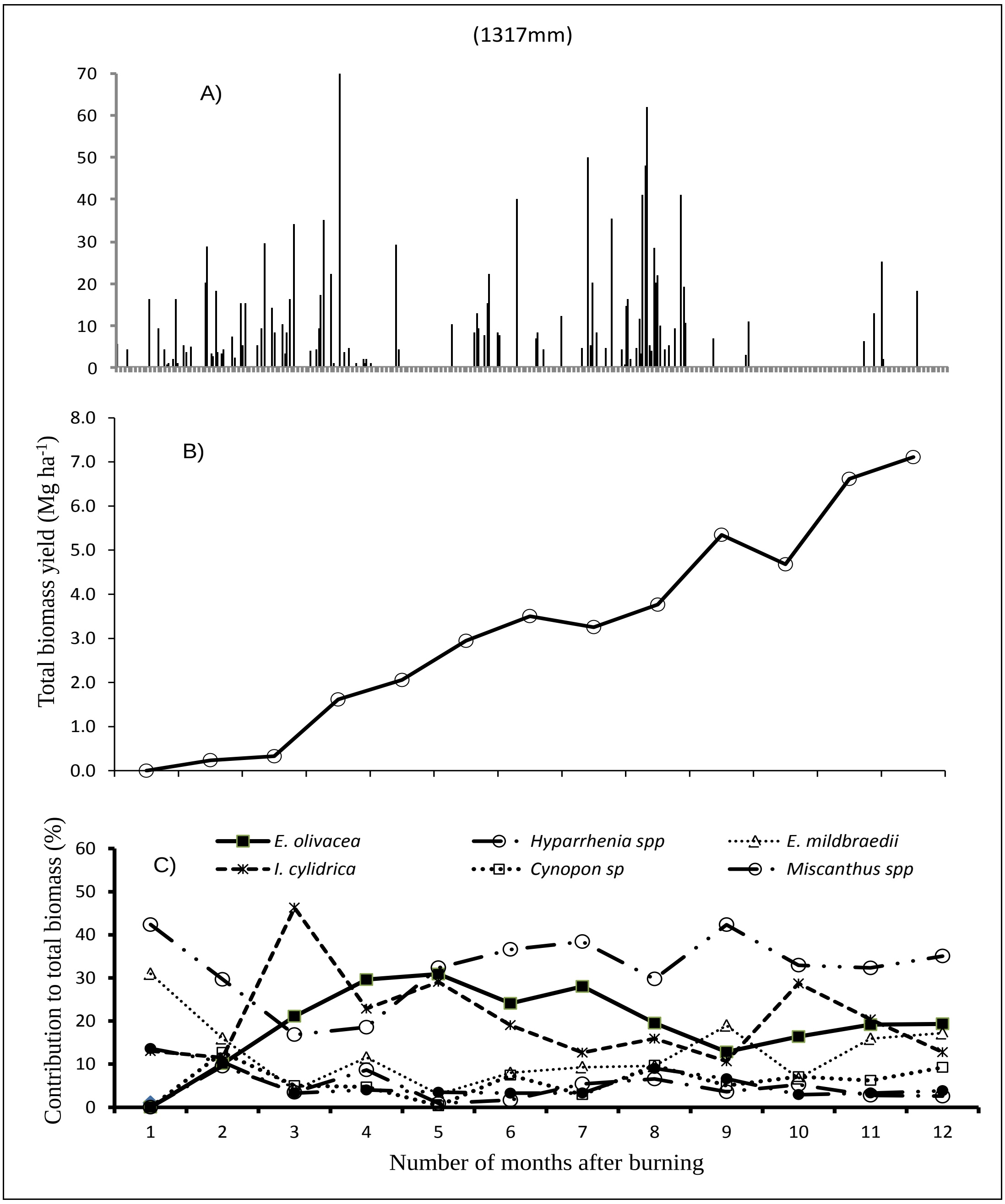

Figure 17: Daily precipitation (mm) (A); Total available standing biomass of grass (DM Mg ha-1 month-1) (B); and Relative contribution of dominant grass species over time to the total standing biomass in the *Rweya* as observed at Nkenge experimental site (C)

Table 23: Monthly standing biomass of various grass species (kg DM ha^{-1}) and their relative contribution to total biomass at Maruku site[a]

Age (MAB)	*E. olivacea*		*Hyparrhenia spp*		*E. mildbraedii*		*L. kagerensis*		*H. dissoluta*		Others		Total
	Mean	RC	Mean	RC	Mean	RC	Mean	RC	Mean	RC	Mean	RC	
1	529	0.73	59	0.11	53	0.13	35	0.04	0	0.00	0	0.00	676
2	1227	0.79	140	0.07	137	0.12	0	0.00	7	0.00	33	0.03	1545
3	1698	0.73	277	0.12	63	0.03	190	0.08	280	0.12	67	0.03	2575
4	1812	0.59	605	0.20	212	0.07	135	0.04	0	0.00	15	0.01	2779
5	2021	0.57	1272	0.35	105	0.03	195	0.05	0	0.00	7	0.00	3599
6	3275	0.61	1641	0.32	198	0.04	212	0.04	0	0.00	0	0.00	5325
7	2844	0.66	1057	0.24	267	0.06	121	0.03	0	0.00	33	0.01	4321
8	1439	0.44	1215	0.34	455	0.12	149	0.05	0	0.00	170	0.04	3428
9	560	0.06	3219	0.69	1185	0.26	155	0.03	0	0.00	76	0.01	5195
10	2253	0.51	1433	0.33	186	0.04	437	0.11	0	0.00	20	0.00	4329
11	2690	0.39	2693	0.39	685	0.09	695	0.11	0	0.00	75	0.01	6839
12	2220	0.30	3698	0.50	567	0.08	918	0.12	0	0.00	0	0	7403
SED	483		553		345		469		69		108		

[a]Data presented as fraction by different sampling months; SED: Standard error of the difference; RC: Relative contribution; MAB: Months after burning

Table 24: Monthly standing biomass of various grass species (kg DM ha-1) and their relative contribution to total biomass at Nkenge sitea[a]

Age	*E. olivacea*		*Hyparrhenia spp*		*E. mildbraedii*		*I. cylidrica*		*Cynopon sp*		*Miscanthus spp*		Others		Total
(MAB)	Mean	RC	Mean	RC	Mean	RC	Mean	RC	Mean	RC	Mean	RC	Mean	RC	
1	0	0.00	100	0.42	73	0.31	31	0.13	0	0.00	0	0.00	32	0.14	235
2	33	0.10	97	0.30	52	0.16	38	0.12	42	0.13	31	0.10	34	0.10	328
3	341	0.21	272	0.17	65	0.04	748	0.46	81	0.05	56	0.03	53	0.03	1616
4	609	0.30	382	0.19	238	0.12	470	0.23	97	0.05	178	0.09	82	0.04	2055
5	909	0.31	953	0.32	89	0.03	856	0.29	10	0.00	25	0.01	102	0.03	2944
6	844	0.24	1282	0.37	280	0.08	666	0.19	260	0.07	58	0.02	114	0.03	3504
7	912	0.28	1250	0.38	302	0.09	412	0.13	95	0.03	176	0.05	107	0.03	3254
8	735	0.20	1120	0.30	361	0.10	598	0.16	365	0.10	247	0.07	339	0.09	3764
9	685	0.13	2264	0.42	1014	0.19	569	0.11	269	0.05	192	0.04	353	0.07	5346
10	766	0.16	1542	0.33	314	0.07	1344	0.29	332	0.07	245	0.05	136	0.03	4680
11	1267	0.19	2138	0.32	1052	0.16	1347	0.20	410	0.06	183	0.03	218	0.03	6615
12	1375	0.19	2494	0.35	1221	0.17	907	0.13	657	0.09	183	0.03	272	0.04	7110
SED	69		106		63		74		43		29		31		

[a]Data presented as fraction by different sampling months; SED: Standard error of the difference; RC: Relative contribution; MAB: Months after burning

Table 25: Biomass available from two months re-growth (kg DM ha^{-1}) of dominant grass species sampled at different dates at Maruku, Bukoba

Date of first sampling	Date of second sampling	*E.olivacea*	*Hyperrhenia* spp	*E.mildbraedii*	*L.kagerensis*	*H. dissoluta*	Others	Total
Oct 8th, 2005	Dec 8th,2005	836	403	191	234	10	29	**1703**
Nov 8th, 2005	Jan 8th, 2006	595	164	154	110	4	13	**1040**
Dec 8th, 2005	Feb 8th, 2006	573	194	98	0	11	34	**910**
Mar 8th, 2006	May 8th, 2006	686	266	89	349	0	31	**1421**
Aug 8th, 2006	Oct 8th, 2006	1366	583	53	44	0	0	**2046**
Sep 8th, 2006	Nov 8th, 2006	1131	592	237	294	83	4	**2341**
Mean		**865**	**367**	**137**	**172**	**18**	**19**	**1577**
SED		184	137	82	114	47	27	
CV(%)		45	79	126	140	549	181	
ANOVA significance		**	NS	NS	*	NS	NS	

NS: Not Significant; * P<0.05; ** P<0.01

Re-growth of Dominant Grass Species after Cutting

Analysis of variance indicated significant variations in re-growth after cutting for *E. olivacea* (*P*<0.01) and *L. kagerensis* (*P*<0.05). However, there were no significant differences among other species: *Hyparrhenia* spp., *E. mildbraedii, H. dissoluta* and the others (Table 25). In general, total biomass of the re-growth was dominated by *E. olivacea* and the *Hyparrhenia* species.

Quality of Grass: Nutrient Contents and Digestibility

Nutrient contents

No significant differences were found in DM content in all grass species whereby values ranged between 92% and 94%. The CP content, however, decreased with maturity. The lowest CP content (33 g kg^{-1}) was recorded in *Hyparrhenia* spp. for the period of July to September (10-12 months after burning) when this grass species was fully mature. The highest CP content (107 g kg^{-1}) was recorded in the mixture of "other species" during January to March (Table 26). Ash contents of grasses varied across species and growing periods in both first cuttings after burning and in the re-growth. For the first cuts, the highest ash content (247 g kg^{-1}) was found in the "other species". However, because of their small contribution to biomass they contribute little to the nutritional needs of livestock. *Hyparrhenia* species had higher (P<0.001) ash content between January through June than *E. olivacea*, *E. mildbraedii,* and *L. kagerensis* (Table 26). The ash contents were within ranges for same species reported elsewhere in the tropics, for instance *Hyparrhenia* species in Brazil (91 g kg^{-1}) and Nigeria (195 g kg^{-1}) (Blair, 1963). Two most important essential mineral elements that was analyzed namely calcium and phosphorus varied significantly (P<0.001) between measurement periods and grass species. There was a significant interaction between sampling periods and species for P content (P<0.05). The highest Ca concentration was found in *E. mildbraedii* during the first six months of growth after burning. The lowest Ca concentration (P<0.001) was observed in *L. kagerensis* during July-September (10-12 months after burning). All species had the least P concentration during 10-12 months after burning except for the "others". Generally, the re-growth had relatively stable P concentrations in all species and growing periods; but there was a significant species and harvest period interaction (P<0.001). There was no significant difference in Ca concentration between species and sampling periods (Table 27).

Digestibility

Dry matter digestibility of *Rweya* grasses varied among the sampling periods and species across both the first-cut and the re-growth, though the variability can be wider in tropical grasses than that observed in this study (Skerman and Riveros, 1990) (Tables 26 and 27). *L. kagerensis* had the highest digestibility (450 g kg^{-1}) in both first-cut and the re-growth. In case of first cut after burning, the digestibility tended to decrease gradually with age.

The forage was of poor quality for grazing with less than 55% digestibility and crude protein (CP) often less than 60 g kg^{-1} DM (Table 26). A CP of 50 g kg^{-1} of DM is often regarded as enough to meet the minimum requirements for grazing animals (Leng, 1990). However, the CP only reached this value during the first six months after burning, thereafter the CP declined to 40 g kg^{-1} of DM or less with increasing maturity of the sward. These results are consistent with the observations of Boutton *et al* (1988) who reported decreasing CP content with maturing vegetation in similar type of grasses. Generally *Hyparrhenia* spp. and *L. kagerensis* had better CP contents (P<0.001) during the first three months of growth after burning while in the re-growth, the highest CP (123 g kg^{-1}) content was measured in the “other species”. For the period between March through April, the highest CP contents were recorded in the re-growth of *E. mildbraedii* and *L. kagerensis* (P<0.001), whereas in May through June the highest CP content was observed in the *Hyparrhenia* species (Table 26).

The digestibility of the re-growth was better in all species between March and April, probably because the good rainfall during the period after cutting stimulated growth of new shoots. The poorest digestibility values were recorded in *E. olivacea*, having similar values in both first cut after burning and the re-growth. Generally, dry matter digestibility of the *Rweya* biomass analyzed *in vitro* was very poor. The peak values of 450 g kg^{-1} decreased over time to 200 g kg^{-1} for the re-growth after burning; and from 564 g kg^{-1} to 203 g kg^{-1} for the re-growth after cutting. When compared to *in vivo* measurements, *in vitro* digestibility may underestimate true digestibility (Kitessa *et al*., 1999; Nsahlai and Umunna, 1996; Armstrong *et al*., 1989). However, this depends on the type of roughages (Forejtová *et al*., 2005). Further, nutritional quality determined from clipped samples may not be an accurate reflection of what the animals select from the rangelands (Shackleton and Mentis, 1992). As such, clipped samples are often lower in crude protein and higher in fibre content compared to fistula samples (Fourie *et al.*, 1986; Prachett *et al*., 1977). However, a relatively constant relationship exists between crude protein in clipped and fistula samples from the same area (Shackleton and Mentis, 1992).

Overall, it appears that the forage in the *Rweya* is of poor quality in terms of digestibility. Acid detergent fiber (ADF) was negatively correlated (r = -0.54) with digestibility, an outcome consistent with results reported from Ethiopia (Bogale *et al*., 2008). Generally, forage quality was highest when the quantity was lowest from the onset of the rains within three months after burning. The best quality-quantity ratio was achieved in November to January, thereafter biomass remained bulky but of low quality because of poor digestibility. Ruminants can only survive on this feed on offer if the best parts of sward are selected by the animals for grazing (De Ridder and Breman, 1993).

In terms of minerals, the standard Ca requirements recommended for ruminants range between 30-10 g kg^{-1}, and for P between 2-4 g kg^{-1} (McDonald *et al*., 1981). Based on these suggested requirements the Ca content of the forage was adequate for the first six months after burning in all species from August 2005 to January 2006. By contrast, the P content was inadequate, except in January to March for *E. mildbraedii.* The "other species" comprised a small fraction of the standing biomass but had high Ca content at all harvests.

The nutritive value of *Rweya* grasses is generally low due to the inherent poor *Rweya* soils (Table 20). One of the first observations on *Rweya* use for grazing dates back to 1937, when the analysis of *Rweya* grass at the Royal Veterinary College, Edinburgh was interpreted as: **"***of all the material analyzed from Africa and elsewhere, this was certainly the poorest in every aspect***" (**Harvey, 1938). Milne (1938) highlighted the unusual degree of infertility of the *Rweya*: **"***the stock carrying capacity of the land is very low, though the bulk of feed remains large…".* It is likely that the low calving rate of cows kept in the free-grazing systems in Bukoba (with an interval of 2.5 years) is associated with poor nutritional quality of the *Rweya* forages.

Table 26: Quality characteristics of forage (g kg^{-1}) of the *Rweya* grass species collected at Maruku, Bukoba.[a]

Species	Growing period	Ash	CP	INVDMD	Ca	P	CF	ADF
E. olivacea	Oct-Dec, 2005	65	61	341	3.5	1.2	493	376
	Jan-Mar, 2006	36	57	379	3.4	1.1	504	426
	Apr-Jun, 2006	44	40	200	2.2	0.8	541	267
	Jul-Sept, 2006	65	40	275	2.1	0.7	550	311
Hyparrhenia sp	Oct-Dec, 2005	80	76	421	4.5	1.3	443	427
	Jan-Mar, 2006	174	51	302	3.8	1.1	500	383
	Apr-Jun, 2006	**186**	39	342	2.2	1.0	572	351
	Jul-Sept, 2006	100	33	284	2.2	0.8	570	311
E. mildbraedii	Oct-Dec, 2005	111	73	**433**	**5.0**	1.7	491	451
	Jan-Mar, 2006	46	59	408	**5.0**	**2.3**	543	424
	Apr-Jun, 2006	50	46	334	3.3	1.1	518	381
	Jul-Sept, 2006	65	41	275	2.1	0.7	550	311
L. kagerensis	Oct-Dec, 2005	96	75	**450**	**4.0**	1.3	462	427
	Jan-Mar, 2006	85	50	274	3.3	1.1	484	366
	Apr-Jun, 2006	96	37	348	2.8	0.9	583	314
	Jul-Sept, 2006	74	36	222	1.9	0.6	597	401
H. dissoluta	Oct-Dec, 2005	2	34	327	3.0	1.6	626	351
	Jan-Mar, 2006	na	na	na	na	na	na	na
	Apr-Jun, 2006	na	na	na	na	na	na	na
	Jul-Sept, 2006	na	na	na	na	na	na	na
Others	Oct-Dec, 2005	147	105	405	**4.5**	1.4	502	452
	Jan-Mar, 2006	**247**	107	364	4.2	1.5	492	395
	Apr-Jun, 2006	123	77	282	3.6	1.1	561	432
	Jul-Sept, 2006	106	73	245	4.4	1.6	564	447
	SED	10.6	10.5	9.5	0.6	0.3	14.6	8.9
	CV (%)	8.8	5	3.4	20.7	26.4	3.3	2.8
ANOVA significance for the differences between the averages of:								
Season		**	**	**	**	**	**	**
Species		**	**	**	**	**	**	**
Species * season		**	*	**	NS	*	**	**

DM: Dry Matter; INVDMD*:* IN Vitro Dry Matter Digestibility; CP: Crude Protein; CF: Crude Fibre; na: not available; NS: Not Significant; ** p<0.001; * p<0.05; Means was based on 15 samples.

[a]Data are based on analyses of composite samples of three months growing periods.

Table 27: Forage quality characteristics (g kg^{-1}) of re-growths of dominant grass species at the Maruku, Bukoba

	Growing period	Ash	CP	INVDMD	Ca	P	CF	ADF
E. olivacea	Oct05-Dec05	39	64	203	4.0	1.0	491	269
	Nov05-Jan06	nd	nd	nd	nd	nd	nd	nd
	Dec05-Feb06	36	54	272	5.0	1.3	487	325
	Mar06-May06	45	63	**402**	3.0	1.0	477	444
	Aug06-Oct06	49	51	320	3.0	2.0	501	340
	Sep06-Nov06	50	42	277	3.0	1.0	526	344
Hyperrhenia spp	Oct05-Dec05	nd	nd	nd	nd	nd	nd	nd
	Nov05-Jan06	nd	nd	nd	nd	nd	nd	nd
	Dec05-Feb06	66	88	412	4.0	1.0	470	440
	Mar06-May06	60	80	**422**	5.0	1.5	444	382
	Aug06-Oct06	49	64	343	3.0	1.1	531	430
	Sep06-Nov06	83	61	308	3.0	0.9	465	374
E. mildbraedii	Oct05-Dec05	52	70	321	5.0	2.0	476	378
	Nov05-Jan06	nd	nd	nd	nd	nd	nd	nd
	Dec05-Feb06	41	77	323	6.0	3.0	470	375
	Mar06-May06	54	83	**411**	4.0	2.0	483	434
	Aug06-Oct06	81	50	354	2.0	1.0	504	407
	Sep06-Nov06	54	50	269	3.0	1.0	596	327
L. kagerensis	Oct05-Dec05	nd	nd	nd	nd	nd	nd	nd
	Nov05-Jan06	nd	nd	nd	nd	nd	nd	nd
	Dec05-Feb06	na	na	na	na	na	na	na
	Mar06-May06	94	90	**450**	1.0	0.2	475	451
	Aug06-Oct06	na	na	na	na	na	na	na
	Sep06-Nov06	51	50	245	5.0	1.4	542	302
Others	Oct05-Dec05	nd	nd	nd	nd	nd	nd	nd
	Nov05-Jan06	nd	nd	nd	nd	nd	nd	nd
	Dec05-Feb06	nd	nd	nd	nd	nd	nd	nd
	Mar06-May06	43	123	**564**	6.0	3.0	528	562
	Aug06-Oct06	na	na	na	na	na	na	na
	Sep06-Nov06	nd	nd	nd	nd	nd	nd	nd
	SED	26.0	9.6	38.2	0.8	0.6	27.6	43.2
	CV (%)	40.7	14.9	11.8	19.8	43.1	5.7	11.7
ANOVA significance for the differences between the averages of:								
Species		***	***	***	**	NS	***	**
Period		**	***	***	**	NS	**	*
Species * period		**	NS	**	***	*	NS	*

DM: Dry Matter; INVDMD: IN Vitro Dry Matter Digestibility; CP: Crude Protein; CF: Crude Fibre; NS: Not Significant; *** P<0.001; **P<0.01; * P<0.05. nd: not determined; na: not available.

Farm Management in Relation to Available *Rweya* Resources

In this farming system, cattle keeping is mainly motivated by manure requirements rather than milk and meat products. Fire has long been used as a management tool in tropical grasslands (Langlands, 1967; Heady, 1960). Although fire stimulates re-growth for grazing, it also destroys valuable mulching grass. Fire also subjects the soil to high temperatures resulting in loss of organic matter, and the bare soil is subject to erosion and rapid drying of the top soil (Boonman, 1993). Fire is typically set at the end of dry season and can be difficult to control and may cause delays in grass re-growth, resulting in bare patches and reduced tiller density (Bloesch, 1999).

Feed supplementation has been proposed to overcome the nutritional limitations imposed by poor quality of available forages e.g. through urea or molasses blocks, poultry litter, commercial concentrates or tree legumes (Mwilawa *et al*., 2008). Supplementation is especially required in the 7^{th} month after burning when grasses are at full maturity and of poor quality. Currently, free grazing cattle are not provided with supplementary feeding but dairy cattle kept by a few farmers who provide maize bran and cotton seed cakes or crop residues from the *Kibanja* and *Kikamba* (FSR, 1990). Cultivation of herbaceous or tree legumes would improve the nutritional quality of forage (Baijukya, 2004; Nichols *et al.*, 2001).

4.4 Model optimization results for virtue farms

Land allocation and yield

The model allocated 0.021ha of *Kikamba* area sufficient to produce at least 50kgDM of sweet potato for all farm types as requirement of household food security in the farming system (Baijukya, 2004). In the absence of cattle, the *Rweya* was not chosen for FT1 having 0.8 ha of *Kibanja*. However, FT2 and FT3 would require 0.24 and 0.53 ha of *Rweya*, respectively, during LR, whereas 0.26 and 0.57 ha would be allocated during SR season. The allocated *Rweya* area is for production of grass for mulching in their respective *Kibanja*. The herbaceous legumes including *T. candida* and *C. grahamiana* were chosen for growing in the *Kikamba* that would supply N and K in form of green manure for optimum *Kibanja* productivity (Table 28). These legumes should be produced from 0.98, 0.72 and 0.41 ha, for FT1, FT2 and FT3, respectively, producing total biomass of 17232, 12740 and 7292 kgDM during the two years period.

Table 28: Optimum yield in DM basis (the objective function) per allocated land to crops for every land use activity[a]

Farm types	Land use type	LUA	Nutrient source (input)	Land allocated (ha)	Production level for seasons (kg)				
					LR1	SR1	LR2	SR2	Total
FT1	*Kibanja*	Banana1	Ltc or Lcg	0.513	205	308	205	308	1026
	(0.8 ha)	B-C3_banana	Ltc or Lcg	0.252	419	628	419	628	2094
		B-C3_Coffee			41	61	41	61	204
	Kikamba	Sweet potato	Weeds	0.021	50	0	50	0	100
			HL	0.979	4308	4308	4308	4308	17232
FT2	*Kibanja*	Banana1	Ltc or Lcg	0.379	152	227	152	227	758
	(0.6 ha)	Banana3	grass mulch	0.023	74	111	74	111	370
		B-C3_banana	Ltc or Lcg	0.187	309	464	309	464	1546
			grass mulch	0.011	19	28	19	28	94
		B-C3_Coffee	Ltc or Lcg		30	45	30	45	150
			grass mulch		2	3	2	3	10
	Rweya	Mulch		LR = 0.238	715	na	715	na	1430
				SR = 0.255	na	1072	na	1072	2144
	Kikamba	Sweet potato	Weeds	0.021	50	0	50	0	100
		HL		0.724	3185	3185	3185	3185	12740
FT3	*Kibanja*	Banana1	Ltc or Lcg	0.217	87	130	87	130	434
	(0.4 ha)	Banana3	grass mulch	0.051	164	245	164	245	818
		B-C3_banana	Ltc or Lcg	0.107	177	266	177	266	886
			grass mulch	0.025	42	63	42	63	210
		B-C3_Coffee	Ltc or Lcg		17	26	17	26	86
			grass mulch		4	6	4	6	20
	Rweya	Mulch		LR = 0.527	1582	na	1582	na	3164
				SR = 0.565	na	2372	na	2372	4744
	Kikamba	Sweet potato	weeds	0.021	50	0	50	0	100
		Ltc or Lcg		0.414	1823	1823	1823	1823	7292

B-C: Banana-Coffee; na: not applicable;

[a]Results for the base run of the model for FT1,FT2, and FT3 in the *Kibanja*, *Kikamba*, and *Rweya* land use types

In order to maximize the productivity, the *Kibanja* requires adequate supply of N and K. At maximum *Kibanja* productivity for example in FT1, FT2 and FT3, the model chose *T. candida* and *C. grahamiana* as green manure legumes to supply all nutrients for FT1, whereas in FT2 and FT3, the model selected *T. candida* and mulch grass (Table 29).

Labour allocation

Model results indicate that labour is not a constraint in this farming system probably because of small land holdings for all farm types relative to available family labour. This is most likely the reason why off-farm activities predominates especially in the high rainfall zone areas where the required labour for farm activities amounts to only 35%, 25%, and 39%, respectively for FT1, FT2, and FT3 of the available family labour (Table 30). These results are consistent with Baijukya (2004) who observed excess labour that would be used in the adoption of legume technology in the *Kikamba* and the off-farm activities.

Through this study, we have managed to find options to enhance the maintenance of the virtual *Kibanja* in the farming system with limited *Rweya* land. We found the differences in resource use efficiency among the three farm types and resulted in different optimal farm systems. Further studies are needed to find out alternative crop activities by considering all aspects of resource use efficiency because results of studies that address farming household level cannot be extrapolated to higher level (say regional level) without additional research.

Table 29: Optimum levels of Nitrogen and Potassium (Kg) needed for production and in the products for FT1,FT2, and FT3,at optimum level of *Kibanja* productivity for banana and coffee in Bukoba District

Farm types	Land use type	Season	Area (ha)	Crop activities	Potassium			Nitrogen				Total yield (Kg DM)	
					need	Source	output	need	Source	output	Balance	Banana	Coffee
FT1	*kibanja*	LR1	0.80		20	Ltc or Lcg	170	14	Ltc or Lcg	48		3120	204
		SR1	0.80	Banana &	30	Ltc or Lcg	256	21	Ltc or Lcg	72			
		LR2	0.80	Coffee	20	Ltc or Lcg	170	14	Ltc or Lcg	48			
		SR2	0.80		30	Ltc or Lcg	256	21	Ltc or Lcg	72			
	kikamba	LR1	0.02	Sweet potato					Ltc or Lcg		-0.6		
		SR1	0.98	Ltc or Lcg					Ltc or Lcg		-375		
		LR2	0.02	Sweet potato					Ltc or Lcg		-0.6		
		SR2	0.98	Ltc or Lcg					Ltc or Lcg		-375		
	rweya		0.00	0		0		0		0			
FT2	*kibanja*	LR1	0.60		20		151	14	Ltc and grass	42		2674	150
		SR1	0.60	Banana &	30	Ltc and grass	227	21	Ltc and grass	63			
		LR2	0.60	Coffee	20	mulch	151	14	Ltc and grass	42			
		SR2	0.60		30		227	21	Ltc and grass	63			
	kikamba	LR1	0.02	Sweet potato							-0.6		
		SR1	0.72	Ltc or Lcg							-277		
		LR2	0.02	Sweet potato							-0.6		
		SR2	0.72	Ltc or Lcg							-277		
	rweya	LR1	0.24	Grass			6			6			
		SR1	0.26	Grass			9			9			
		LR2	0.24	Grass			6			6			
		SR2	0.26	Grass			9			9			
FT3	*kibanja*	LR1	0.40		21		127	14	Ltc and grass	35		2348	106
		SR1	0.40		31	Ltc and grass	191	21	Ltc and grass	52			
		LR2	0.40		21	mulch	127	14	Ltc and grass	35			
		SR2	0.40		31		191	21	Ltc and grass	52			
	kikamba	LR1	0.02	Sweet potato							-0.6		
		SR1	0.41	Ltc or Lcg							-159		
		LR2	0.02	Sweet potato							-0.6		
		SR2	0.41	Ltc or Lcg							-159		
	rweya	LR1	0.53	Grass			13						
		SR1	0.57	Grass			19						
		LR2	0.53	Grass			13						
		SR2	0.57	Grass			19						

Ltc= *Tephrosia candida* ; Lcg= *Clotaralia grahamiana* ; SR= short rain season; LR= long rain season

Integration of crop activities and livestock

The maximum number of cattle allocated for the farming household with average *Kibanja* of 0.8 ha is 2 that need about 1 ha of *Rweya* for grazing animals. Manure production from these animals are 969 and 1357 kgDM in the LR and SR seasons, respectively, which is adequate for maximum *Kibanja* productivity (Table 31).

Table 30: Maximum values of required labour (hours per season) per land use for FT1,FT2, and FT3 where there is no cattle among the farming households

Farm types	Average *Kibanja* area (ha)	Total labour per year (hours)	LUA	maximum labour needed (hours per season)				
				LR1	SR1	LR2	SR2	Total
FT1	0.8	5568	*kibanja*	155	232	155	232	774
			kikamba	303	295	303	295	1196
			rweya	0	0	0	0	0
			Livestock	0	0	0	0	0
			Total	**458**	**527**	**458**	**527**	**1970**
FT2	0.6	7488	*kibanja*	121	182	121	182	606
			kikamba	226	218	226	218	888
			rweya	71	107	71	107	356
			Livestock	0	0	0	0	0
			Total	**418**	**507**	**418**	**507**	**1850**
FT3	0.4	4416	*kibanja*	81	121	81	121	404
			kikamba	133	125	133	125	516
			rweya	158	237	158	237	790
			Livestock	0	0	0	0	0
			Total	**372**	**483**	**372**	**483**	**1710**

Table 31: Optimum *Kibanja* productivity while integrated with livestock activities

Characteristic	Growing seasons			
	LR1	SR1	LR2	SR2
Number of grazing cattle	2	2	2	2
Rweya land area needed (ha)	0.979	0.979	0.979	0.979
Kikamba area (ha)	0.021	0.021	0.021	0.021
Labour need for livestock activities (hours $season^{-1}$)	92	128	92	129
Labour needed for *Kikamba* (hours $season^{-1}$)	9		9	
Rweya forage production (Kg DM $season^{-1}$)	1469	2056	1469	2056
Nutrients production (Kg $season^{-1}$):				
Potassium	28	39	28	39
Nitrogen	24	33	24	33
Manure production (Kg DM $Season^{-1}$)	969	1357	969	1357
Kikamba yield (Kg DM $Season^{-1}$):				
Sweet potato tubers	50		50	
Sweet potato residues	64		64	
Weeds		42		42

General discussion on model outputs

Objective functions

This study has explored for options of maintaining the productivity of the *Kibanja* in the context of diminishing *Rweya* land accessible to farming households as main supplier of the fertility replenishing inputs to the *Kibanja*. The results presented in this chapter demonstrate that farm resource endowment has strong impacts on possibilities of sustainable productivity of the *Kibanja*. The low fertility status of *Rweya* land and the associated rapid declining of the area under this land use type are the principal constraints to productivity of the system especially in the high rainfall zone where high leaching is the basis of losses of mobilized nutrients (Deugd, 1994). Likewise, continuous grazing, cutting of grasses, burning and lack of collective management following changes of tenure systems are among the factors threatening the sustainability of the farming system. Moreover, available options for keeping the balances of Nitrogen and Potassium positive in the *Kibanja* farming system have been determined since these nutrients are the two most important elements in the system. The results of the model shows that with present production environment for the three virtual farm types having average of *Kibanja* area i.e. 0.8, 0.6, and 0.4, respectively, are able to maintain the productivity of *Kibanja* using herbaceous legumes *T. candida* and and *C. grahamiana* as source of nutrients that are essential as inputs in the productivity of the system.

Farmers with access to farm yard manure (FYM) are able to establish and maintain the productive *Kibanja*. About 15% of farmers own cattle in this farming system. This means most *Kibanja* are established and maintained without manure or fertilizers. Often, only mulch grasses from the *Rweya* with low nutrient value are applied. We conclude that the *Kibanja* mobilizes and recycles intrinsic soil fertility, and that there is hardly a question of accumulation of nutrients. Although most farmers depend on initial quality of the soil, which apparently explains the inherent variations in *Kibanja* productivity, without external inputs such as adequate FYM, fertilizer or organic manure, nutrient deficiencies will continue to hamper the productivity more and more with time. In all farm types, weeds were chosen by the model as the input for sweet potato production, as it is normally practiced by farmers. Grass mulch was chosen for use in the mixture of banana and coffee in the third technology level for only FT2 and FT3.

General characteristics of the farming system

The highland bananas (*Musa sp*) and coffee (*Coffea canephora*) makes the most important food and cash crops, respectively, in Bukoba District. Irrespective of the accuracy of the yield estimations and the extent of yield decline, the widely reported actual banana yields on smallholder farms that is 5−30 Mg ha^{-1} yr^{-1}, are far below the estimated potential yields (> 70 Mg ha^{-1} yr^{-1}) (Nyombi, 2010). Coffee on the other hand has the actual production level of 0.225 Mg ha^{-1} $year^{-1}$ (Mwijage *et al*., 2009), while the potential production level is estimated at 5.0 Mg ha^{-1} $year^{-1}$ in pure stand with 1000 trees ha^{-1} (Magina, 2005). On average, the consumption of bananas in the District is estimated at 767 Kg per person per year (Rugalema, *et al*., 1994). Nevertheless, there is increasing concern over persistently low and yet declining productivity level among smallholder farmers over the last 40 years for all these crops (Rugalema *et al*., 1994; Nkuba *et al*., 2003; Baijukya, 2004). Along with the causes of this crisis contain change of use for grasslands (*Rweya*) with other uses other than the traditional ones such as tree planting by few wealthy farmers (Mwanukuzi, 2009). Low yields are in fact mainly attributed to poor soil fertility, pest pressure (banana weevil - *Cosmopolites sordidus*; nematodes - *Radopholus similis*, *Helicocotylenchus multicinctus* and *Pratylechus goodeyi*), diseases (black sigatoka - *Mycosphaerella fijiensis*, banana wilt, banana streak virus, banana bacterial wilt) and general poor crop husbandry (Gold *et al*., 1999). Other causes of low yields involve abiotic factors such as population pressure that increases the competition over the land resources, and poor pricing systems of farm products.

Table 32: Summary of general characteristics of the farming system in relation to use of grasslands in Bukoba District

Characteristic	Description
Farming zone	Mainly two: low rainfall zone (LRZ) and high rainfall zone (HRZ).
Main crops	Highland bananas (*Musa* sp.) and Coffee (*Coffea canephora*)
Other crops	Beans (*Phaseolus* sp.), cassava, sweet potatoes, maize, taro, yams, pumpkins, fruits, trees, and vegetables.
Land use types and distribution	Mainly three: Homegarden *(kibanja* - 28%*),* annual crop fields *(kikamba* - 7%*),* and grasslands - *rweya* - 25%*);* others - 40%.
Grassland use	75% of smallholders cultivate annual crops on the grassland; 100% collect mulch grass from the *rweya* for their farms.
Cropping seasons	Four (Long rain - January through May: *kanda* and *toigo*)*;* Short rain - June through December*: kyanda* and *muhanguko*)
Rainfall distribution and drought risk	LRZ (900 - 1500 mm); HRZ (1500 - 2200 mm) per year
Livestock density	3 head of cattle per ha as an optimum in the *Rweya* land
Cropping area per household	Usually ranges from 0.2 to 1.0 ha with average of 0.5 ha.
Land tenure	*Kibanja* : (74% traditionally owned by inheritance; 12% purchased)
	Rweya : 39% traditionally acquired by inheritance; 24% purchased)
Average crop division	Highland bananas (33%), Coffee (22%); Beans (15%); Roots and tubers (22%); others 8%)
Farm labour	Family- based and or hired
Mulch use (range per farming	LRZ (5 - 28 Mg ha^{-1}); HRZ (1 - 15 Mg ha^{-1})
Mechanization	Negligible
Livestock problems	Shortage of grazing areas due to shrinkage of the *rweya* and
Diversity of farming households	Self categorization - 4 resource groups (RG):
	HRZ: Wealthy-RG1 (15%); Average-RG2 (19%); Poor-RG3 (33%); Very poor-RG4 (33%).
	LRZ: Wealthy-RG1 (13%); Average-RG2 (14%); Poor-RG3 (63%); Very poor-RG4 (10%).
	Principal component analysis - three farm resource groups (FRG):
	wealthy (FRG_1); medium (FRG_2); and poor (FRG_3)
Manure use (Mg ha^{-1} $year^{-1}$)	HRZ: FRG_1 (10.5), FRG_2 (4.2), FRG_3 (0)
	LRZ: FRG_1 (0.5), FRG_2 (0.2), FRG_3 (0)
Mulch use per farm (Mg ha^{-1} $year^{-1}$)	HRZ: FRG_1 (11), FRG_2 (10), FRG_3 (1)
	LRZ: FRG_1 (5), FRG_2 (4), FRG_3 (2)

Although improved technologies are available in different ecological regions including the use of organic fertilizers which are the most important as amendments in soil fertility management, these technologies are not fully exploited by smallholder farmers in this farming system. Main soil fertility management practices applied by farmers in Bukoba include organic fertilizers to the *Kibanja* in the form of mulch (*Rweya* grasses, crop residues, and kitchen refuse) or animal manure (i.e. cattle, goats, pigs) that improve and maintain the soil fertility management even if the initial fertility status is naturally very low.

The debate on the implications of changing land tenure systems and their effect on land management and productivity is one of the long-standing issues in both theoretical and empirical studies in rural development (Ray, 1998; Peters, 2009). Basically, land tenure systems should allow for better land management practices in both the short and long term and therefore contribute towards sustainable agricultural development. As a matter of fact, land use rights determines the accessibility to and use of communal land for livestock grazing or availability of organic resource materials such as mulch for use in most mixed smallholder systems of Sub-Saharan Africa (Giller *et al.*, 2009). This is particularly true for free grazing systems which mainly rely on communal resources and traditional grazing management systems.

As observed in this study, the administration of the land in most rural areas of sub-Saharan Africa was relegated in the realm of customary law under tribal authorities. In the recent years, however, land reforms and reorganization of tenure relations in most areas have had two principal objectives: to achieve social justice by removing politically embedded capital-labour relations and to promote greater productivity. Following such reforms, several countries have achieved impressive rates of growth in Agricultural output particularly in Asia. On the basis of this experience, development specialists have tended to recommend land tenure conversion, introducing individual property rights as a means of inducing increased agricultural productivity (World Bank, 1974).

The characterization of the farming system involves categorizing farms by inferring from farm characteristics, often using multivariate analysis techniques (Duvernoy, 2000). Although there were broader classifications among farming households in Bukoba District in the past, no detailed classification was attempted based on farm production characteristics and household's resource endowments, thus the initial attempt was done in this study.

The four farm types identified by farmers themselves were distinguished mainly by domestic assets, livestock ownership and labour relations. However, through multivariate analysis techniques using additional variables defined by the research team including land holding, socioeconomic attributes and the use of *Rweya* resources, three categories of farming households were identified from which representative farms for subsequently detailed analysis were based.

This study has revealed that the existing variability among farming households in Bukoba is influenced by several factors. Besides such factors like off-farm opportunities, population density, and biophysical factors, livestock components in the farming system is important for further intensification especially with regards to present increasing land pressure. In fact sources of income and main expenditure constitutes to functional farm typology within the farming system. In this study we found that the range of variability among farming households is very wide, although major drivers to this diversity defined by wealth ranking seem to be based rather on visible physical assets than variables having direct influence to farm management practices.

Resource use efficiency and farm productivity

The complexity of problems associated with interactions involved in availability, management, and exploitation of common grassland resources that are important in the productivity of home garden were examined. Empirical evidence from field survey and measurements reveals the need to consider maintenance of soil fertility as a key issue in agricultural intensification. Grassland ecosystem is; in fact, essential resource for crop production and livestock feed production through provision of feed resources thus is an important land use type for the sustainability of entire farming system (Mwanukuzi, 2009). Generally, in areas where there is mixed farming system comprising crops and livestock component, the constraints to soil fertility replenishment are more severe because of competition between the allocations of land for the two components. Intensification under the influence of increased pressure on the land restricts availability of manure although some arable farmers keep their own livestock for manure production, but many farmers do not possess suitable feed resources. The inherent poor quality of available feed resources including low digestibility, low protein content, and low mineral contents, limit the utilization of these resources by ruminants. The option of treating the fodder with, for example, urea or alternatively supplementation with protein-rich concentrates is not available to all farmers, and where concentrates are used, they are fed mostly to dairy lactating animals. The limited availability of high-quality feed resources also encourages supplementation of livestock feeds, and as a result, there is increasing interest in the use of legumes as supplements to improve the diet quality and provide better-quality manure as suggested by Savadogo (2000). Unlike extensive livestock systems where there is no direct return of manure to food cropping areas, as all manure is left on the grazing lands. However, manure deposited where the animals are housed overnight can be more readily collected and used. Also, in this system, animal production component are often inefficient converters of feed into animal products.

The role of mulch in the system

As we have observed in this study, all farming households collect grasses for mulch from the *Rweya* for their farms. However, the main purpose of mulching differs between the farming zones (i.e. high rainfall zone and low rainfall zone). In the high rainfall zone; for example, according to farmers, the primary purpose of mulching is mainly to combat weeds and improve soil fertility. In these hilly areas with high precipitation, application of mulches to crops may alleviate some of the problems such as erosion, runoff of agrochemicals, and leaching.

In the low rainfall zone, mulching primarily is applied to conserve soil moisture although other benefits like weed suppression are also provided. Despite *Rweya* grass from the grassland that are used as mulch, also old banana leaves and the unwanted banana suckers are often cut at the end of rain season (May-June) for use as mulch because during the dry season (June-September), bananas lose most of their dead leaves leaving only the green leaves.

CHAPTER FIVE

GENERAL CONCLUSION AND RECOMMENDATIONS

5.1 General conclusions

If the current trend of declining productivity in the District is left, banana production will be very low, so that dependence on food imports will be inevitable. It is more likely that the present trend towards crop diversification will continue. More and more root crops and cereals should compensate for the gap created by banana shortfalls. However, as pointed out earlier, it is doubtful whether the fragile system could sustain such a change for long.

Another option is the rehabilitation of the system. There is broad political support for this option due to strong attachment of indigenous people to their preference to banana as food crop, and the vested interest of out-migrants who expects to come back. Rehabilitation, however, would require a large number of interventions. None of these will be effective by itself, but each might make a contribution in the right direction. Rehabilitation measures may include: i) Reforming land tenure systems ii) Improving soil fertility and management using alternative technologies such as mineral fertilizers; iii) Improving agronomic practices in crop husbandry for example by integrated control of crop pests and diseases; and iv) Reforming and improve pricing systems for crops and livestock products so that farmers can get more cash that can be used for investment in agricultural production.

The possibilities for expansion of the cultivated *Kibanja* area are very limited especially in the high rainfall zone areas. In old settlement areas, however, transformation of *Rweya* to *Kibanja* could be done, hitherto requires prohibitive investments. In fact, tea is grown in the *Rweya* as alternative crop with application of mineral fertilizers by some farmers in the HRZ, and trees are grown by few wealthy farmers. Although the wide swamps and valley bottoms have a theoretical potential for expansion of farm land, those areas would need extensive drainage works, and yet, it is not clear of what crops could be suitable, and thus further research is necessary on this area.

Historically, expansion of an area under agriculture was an important source of crop production growth. However, further opportunities for area expansion are now exhausted except in the LRZ and some parts of HRZ where rural population densities are still low. The increase in cropping intensity may offer a solution to the problem of how to expand area. This may require adoption of soil fertility management technologies including introduction of legume species in the grasslands as suggested by Gallegos (2003), though this option is potentially an expensive attempt. However, further research on policy debate are desirable on these issues, as the evidence observed in this study on the resource tenure in Bukoba District is approaching a critical point in history.

5.2 Summary of the main findings and recommendations

Tenure systems

This section discussed how agro-ecological processes and tenure arrangements are intertwined and examines how the productivity of individually-owned land (*Kibanja*) in Bukoba, Tanzania, is critically depending on common land (*Rweya*). Future tenure reform programs that aim to increase land productivity but that ignore such interdependencies, are likely to yield the opposite from what is envisaged – i.e. productivity decline. The historical co-existence and persistence of different land tenure arrangements for different land uses – as elaborated for this farming system – challenges evolutionary models of land tenure change, which view communal and individual access to land as mutually exclusive and successive categories. As the Bukoba case reveals, it is important for any policy change to take the structure of the farming system into account, as it ultimately shapes the productive use of the land.

Although population pressure may have contributed to competition over available land based resources in Bukoba District, the changes in socioeconomic development may have, as well, induced changes in tenure arrangements and speeded-up the process of change in land use on *Rweya* as observed in recent decades. As a matter of fact, many African governments are involved in land tenure reform in smallholder farming systems. This is particularly true where government institutions have taken over or partly substituted customary systems led by chiefs and other community authorities. As this study has shown, integration of such 'modern' and customary regulatory systems is crucial, even if their jurisdictions relate to different land uses that may be highly interdependent. Thus any (partial) land tenure reform is unlikely to succeed if it is founded on inadequate information regarding the prevailing agro ecological structure and processes of the farming system. Research prior to policy formulation is necessary, and research should be maintained at the implementation and evaluation stages to permit proper monitoring of outcome on land resources.

In order to reduce the negative consequences of increased population pressure on *Rweya,* alternative technologies such as zero grazing where farmers grow their own fodders or mulch materials instead of depending on common land resources are one of the options. The use of leguminous fodders or cover crops that fix nitrogen from the air and thus add nutrients to the system may also assist in sustaining productivity of the system. Without external inputs such as mineral fertilizers, it is likely that soil fertility will decline further, perhaps causing a permanent shift away from production of highland banana to arable crops. Depending on the sale price of industrial fertilizer inputs, intercropping of coffee in the *Kibanja* may be an option that can economically justify for the use of fertilizers.

According to the Village Land Act, the maximum limit to land holding is set at 20 ha per person residing in a village, yet there is no legal minimum limit of land holdings under Tanzanian land laws. Given that population density is increasing rapidly in Bukoba, as in other regions of Tanzania, land fragmentation and landlessness are also increasing. Simultaneously, the area of *Kibanja* per household is decreasing. Policy measures to intensify agriculture, the stimulation of out-migration to places where land pressure is less acute, or the provision of alternative employment opportunities outside agriculture may therefore be more relevant for maintaining the sustainability of farming systems than a continued pre-occupation with land tenure reform.

Farm typology

The results presented in this section were based on surveys of smallholder farmers in two villages in Bukoba District. Selected households were believed to be representative of the area(s) which is constrained by land shortage and low land productivity per unit of available land. Therefore, the results are likely to reflect the situation confronted by rural farming population in the District. Studies on characterization of farming systems have a practical usefulness as they not only improve understanding of inherent variability among farming households, but also can help to explore future opportunities for farmers to invest in new strategies and technologies.

The key results of this study indicate that categorization of farms based on the wealth of a household defined by wealth ranking seems to be based more on visible physical assets as defined by key informants such as type of the house or owning transport facilities rather than those variables that have direct influence on farm management practices. In this case the discriminatory variables may not be relevant to agricultural innovations. Moreover, the proportion of farms falling within each resource group may be expected to vary at different locations depending what local community perceives to constitute wealth and may depend on the research objectives. For example, in general sense there were no substantial differences between RG3 and RG4 for both the HRZ and LRZ in terms of farm characteristics and constraints. Characterizing the farm with PCA revealed main variables that determine the main drivers to farm variability such as land holding, labour, farm enterprises, access and use of common property resources such as mulch from the *Rweya*, and the dependence on off-farm activities and off-farm income. The wealth ranking of households indicated that major characteristics can be generalized consistently across the zones and the information can suffice quick overview of general variability within the farming system but without guarantee for retrieving similar results under detailed analysis depending on researchers' objectives.

Organic resource inputs are important components for sustainable farm productivity in the Bukoban banana-based cropping systems through their short term nutrient supply, moisture conservation, weed suppression, and long term contribution to soil organic matter formation. Their roles are not only in contribution to soil fertility improvement and farm productivity but also for promotion of sustainable agriculture and protection of the environment. This study has shown, however, that because of small land and poor land productivity, the majority of farmers participate in off farm activities that bring them some off farm incomes. Similarly, many households are net buyers of food. These complex scenarios require a multi–stakeholder approach such as farmers, researchers, and policy makers. Low yields from existing technologies, in combination with apparently constrained land resources for many households in this farming system, implies that food must be available for purchase if these households are to meet their consumption needs. However, having food in the market needs effective demand which in turn required buyers to have a strong purchasing power. For example, income earned through off-farm works or from cash crops sold need to be sustainable as a means of enhancing food security and improved livelihoods.

Meanwhile, further research is needed to assess variability within the farms so as to come up with detailed factors that derive to spatial resources allocations. Moreover, further research on the potential productivity of these *Rweya*-based organic resources relative to the demand by different functional resource groups would provide a useful insight for policy enrichment.

Rweya productivity

The three main land use types in Bukoba District (*Kibanja*, *Kikamba* and *Rweya*) and the livestock sector form an integrated system to support rural livelihoods. In fact, the productivity of *Kibanja* currently mainly depends on *Rweya* as main source of organic matter in the form of manure and mulch. The *Rweya* grasses are also important for thatch, as carpet and for processing banana juice. However, population growth and privatization of the *Rweya* where individuals plant of trees inserts increasing pressure on availability of grasses for mulching in the *Kibanja* (Mwanukuzi, 2009).

In remote parts of East Africa, such as Bukoba, options to deal with declining soil fertility are not within easy reach and are often not economic. In the Bukoban farming system, *Rweya* resources are used by farmers to transfer nutrients in manure to their crop fields but livestock ownership is increasingly restricted to the wealthier farmers (Baijukya *et al.*, 2005). With the decreasing availability of grasses, it is likely that only few wealthy households who have cattle and adequate labour or capital to use mulch will sustain the transfer of nutrients to their farms. Alternatively, farmers might opt to plant forages to provide mulch and fodder for their livestock and different competing uses of *Rweya* grasses co-existing within the farming system.

Quality of grasses

Overall, it appears that the forage in the *Rweya* is of poor quality in terms of digestibility and mineral contents. However, forage quality was highest when the quantity was lowest from the onset of the rains when the best quality-quantity ratio was achieved in November to January, thereafter biomass remained bulky but of low quality because of poor digestibility.

In terms of minerals, the standard Ca requirements recommended for ruminants range between 30-10 g kg^{-1}, and for P between 2-4 g kg^{-1} (McDonald *et al*., 1981). Based on these suggested requirements the Ca content of the forage was adequate for the first six months after burning in all species from August 2005 to January 2006. By contrast, the P content was inadequate, except in January to March for *E. mildbraedii.* The "other species" comprised a small fraction of the standing biomass but had high Ca content at all harvests.

Sustainability of the system

Most countries in sub-Saharan Africa and in marginal production environments across the developing world continue to experience low or stagnant agricultural productivity, leading to rising food deficits and high levels of poverty. This is largely a result of multifactor including, among others, continuing rapid population growth making the highest in the world with fast land degradation (Badiane and Delgado, 1995). However, in order to increase or improve agricultural productivity in this vulnerable areas, three requirements have been suggested i.e. (i) reversing soil-fertility depletion, (ii) intensifying and diversifying land use with high-value products, and (iii) an enabling policy environment for the smallholder farming sector through improved road infrastructure, land tenure systems, access to education, credit, inputs, markets, and extension services, (Sanchez and Leakey, 1996).

Bukoba District is typical of many places in east African highlands especially in western Kenya, eastern and southern Uganda, and in Rwanda. Although the agricultural potential is high in these areas, the productivity is constrained severely by nutrient depletion reported as one of major cause of chronic food insecurity (Shepherd *et al*., 1997; Sanches, *et al*., 1996). The overall objective of this study was to explore for socioeconomic and biophysical variables that accelerates soil fertility depletion in the region which subsequently hamper the productivity of banana-based farming system with special emphasis placed on the role of grassland resources in the farming system. The objective of this section, therefore, was to bring together the findings and lessons gained in entire specific objectives towards overall objectives of this thesis.

Since food security in many countries remains an important objectives in the coming several decades (Roetter and van Keulen,2007), there is a need to increase agricultural productivity per unit land area with more sustainable production methods being added to the research agenda. In this case, an agricultural production system that combines high resource use efficiency for high yields is paramount in order to meet the challenges that the future provides.

5.2 General recommendations for future prospects of the farming system

One main causes of loss of soil fertility in SSA is continuous intensive exploitation of natural resources coupled with decreasing availability of manure. The gradual decline of good husbandry practices as a result of spending more time away from the farm for off-farm employments by smallholder farmers aggravates farm management practices. In Bukoba farming system, the cropping land is exposed to heavy rain during the season which exacerbates heavy leaching, with rapid decline of soil organic matter content. As result chemical and physical properties of soils deteriorate rapidly, erosion sets in while reducing nutrient availability to crops. In the end, the highly productive man-made soils, developed with great efforts is lost completely. One possible way of mitigation of the future of banana farming system is annual cropping. Farmers are increasingly turning into root crops (especially cassava and sweet potatoes) and maize. In fact there is more opportunities at stake than just replacement of the crop by another.

Another prospects lies on grazing rights. There is a need to be defined in some areas by giving livestock owners private rights, or collective rights that might be coordinated by administrative authorities. In the second scenario, the rights may not be exclusive to local users alone. In fact, the habit of livestock herders to move in communal grazing areas will soon cease to be a viable one in Bukoba District. The banana-based cropping system should therefore be preserved not only because is a productive and ecologically sound system, but also because under the prevailing natural and socio-economic environment there in no quick fix alternatives.

At farm level decisions have to be made to keep the farm area as a whole in good soil fertility conditions to ensure sustainable productivity. As variability in soil fertility occurs within the farm, the farmer has to decide where, when, how often, and how much fertilizing materials should be applied. At farm level, issues to be considered are the manure production, compost production, and application of materials such as lime or other cation containing acidity-neutralizing materials (e.g. ash). Furthermore, the farmer has to know where the need for fertilization is highest. This depends on the yield level, the type of crop and soil, and the resource endowments level.

Population increase

Bukoba District is one area with the highest Population densities in Africa and have been reported to hamper farm productivity and even threaten for survival of the system (Bosch and Bantje, 1989). Population pressure results to acute land shortage, fragmentation of the holdings, high rates of outmigration and reliance on off-farm activities. Since some farmers neglect their land and prohibits other farmers with less land or landless from utilizing their land, appropriate policies are necessary that would regulate for land accessibility among community members. This arises from the fact that social conflicts between contestants for the use of land has been on an increasing frequency in recent years. Among a number of incidences are several litigations, mostly resolved in local courts, and administrative adjudications. From the fact that conflicts are increasing and that are related to natural resource matters, this implies an inability of market mechanisms to resolve the competition between the alternate land users in a current market-based economy.

Grossary

"Emyaka" - Anything eaten in the household besides banana literally including root crops such as sweet potatoes, cassava, and yams.

REFERENCES

Achard F, Banoin M. (2003). Fallows forage production and nutrient transfers by livestock in Niger. *Nutrient Cycling in Agroecosystems.* 65: 183-189.

AOAC. (1990). Association of Official Analytical Chemists. Official Methods of Analysis. 15th Edition. Washington, D.C.

Akresh, R and Verwimp, P.(2006). Civil War, Crop Failure, and the Health Status of Young Children IZA Discussion Paper No. 2359. [http://ssrn.com/abstract=939004] Site visited on 10/02/2013.

Aktar, W, Sengupta, D. and Chouthury, A. (2009). Impact of Pesticide Use in Agriculture: Their benefifs and hazards. *Interdisciplinary toxicology* 2(1):1-12.

Armstrong R.H, Common T.G, Davies G.J. (1989). The prediction of the diet of sheep and cattle grazing indigenous hill plant communities by *in vitro* digestion, faecal nitrogen concentration or indigestible. acid-detergent fibre. *Grass and Forage Science.* 44**:**303-313.

Atwood D. (1990). Land Legislation in Africa: The Impact on Agricultural Production. *World Development* 18 (5)**:** 659-671.

Azam, F. Mal1k K. A. and Sajjad M. I. (1985). Transformations in soil and availability to plants of N applied as inorganic fertilizer and legume residues, *Plant and Soil.* 86, 3-13.

Badiane, O., and C.L. Delgado.(1995). A 2020 vision for food, agriculture and the environment in sub-Saharan Africa. *Food, Agriculture and the Environment Discussion Paper 4*. International Food Policy Research Institute, Washington, DC.

Baijukya F.P, Ridder N de, Masuki K.F, Giller K.E. (2005) .Dynamics of banana-based farming systems in Bukoba District, Tanzania: changes in land use, cropping and cattle keeping, *Agric. Ecosyst. & Envir*. 106 (4): 395-406.

Baijukya F.P and Steenhuijsen Piters Bde. (1998) 'Nutrient balances and their consequences in the banana-based land use systems of Bukoba District, Northwest Tanzania', *Agric. Ecosyst. & Envir*. 71 (1-3): 147-158.

Baijukya, F.P. (2004). *Adapting to Change in banana-based farming systems of northern Tanzania*. PhD Thesis. Wageningen University, The Netherlands.

Barrett, C.B, Marenya, P.P, Mcpeak, J., Minten, B., Murithi, F., Oluoch-Kosura, W., Place, F., Randrianarisoa, J.C., Rasambainarivo, J., Wangila, J. (2006). Welfare dynamics in rural Kenya and Madagascar. *J. Dev. Studies* 42, 248–277.

Bationo A, Kihara J, Vanlauwe J.B, Waswa B and Kimetu J. (2007). Soil organic carbon dynamics, functions and management in West African agro-ecosystems, Agricultural Systems 94(1): 13-25.

Bekunda M.A, Nkonya E, Mugendi D. and Msaky J.J. (2004). Soil fertility Status, Management, and research in East Africa. *Eastern African Journal of Rural Development* .20(1): 94-112

Blair R.A .(1963). Miscellaneous papers, Samaru (Nigeria), No. 1.Animal feed resources information system. http://193.43.36.103/ag/AGA/AGAP/FRG/afris/Data/106.HTM (Site visited on 23/08/2012).

Braak C.J.F ter. (1995). Ordination. In: Jongman R.G.H, Braak C.J.F. ter, Tongeren O.F.R van (eds.) *Data analysis in community and landscape ecology*. Cambridge University Press, Cambridge, UK. pp. 91-173.

Braak C.J.F ter, Smilauer P. (2002). CANOCO Reference manual and CanoDraw for Windows User’s guide: Software for Canonical Community Ordination (version 4.5). In: Microcomputer Power, Ithaca, NY, USA. P. 500.

Breman, H. and Debrah, S.K. (2003). *Improving African food security*. SAIS Review vol. XXIII (Winter-Spring) (1), 153 – 170.

Bogale S, Melaku S.H, Yami A. (2008). Influence of rainfall pattern on grass/legume composition and nutritive value of natural pasture in Bale Highlands of Ethiopia. *Livestock Research for Rural Development* 20 (No. 3).

Boonman J.G. (1993). *East Africa's Grasses and Fodders: Their Ecology and Husbandry*. Dordrecht/Boston/London. Kluwer Academic Publishers.

Bloesch U. (1999). Fire as a tool in the management of a savanna/dry forest reserve in Madagascar. *Applied Vegetation Science* 2:117-124.

Boutton T.W, Tieszen L.L, Imbamba S.K. (1988). Seasonal changes in the nutrient content of East African grassland vegetation. *African Journal of Ecology* 26 (2):103-115.

Bosch, C.H. and Bantje, H. (1989). Annotated bibliopgraphy of Kagera Region. Lake Zone FSR project, Working paper No.2.

Chambers R. (1994). The origin and practice of participatory rural appraisal. *World Development* 22: (7), 953-969.

Chambers R, Jiggins J. (1987). Agricultural research for resource poor farmers. Part 1: Transfer-of-Technology and farming systems research. *Agriculture Administration and Extension* 27: 35-52.

Chamberlain, A.T., Wilkinson, J.M. (2002). *Feeding the dairy cow*. Charcombe Publications, UK. 241pp.

Chimhowu A and Woodhouse P. (2006). Customary vs Private Property Rights? Dynamics and Trajectories of Vernacular Land Markets in Sub-Saharan Africa, *Journal of Agricultural Change* 6(3): 346-371.

Cho, K.M. and Zoebisch, M.A. (2003). Land use changes in the upper Lam Phra Phloeng Watershed, Nothern Thailand: Characteristics and driving forces. *Journal of Agriculture and Rural Development in the Tropics and Subtropics* 104 (1), 15-29pp.

Clayton W.D. (1970). Gramineae (part 1). In E. Milne-Redhead and R.M. Polhill (Eds.). *Flora of Tropical East Africa*. East African Community.

Clayton W.D, Phillips S.J, Renvoize S.A. (1974). Gramineae (part 2). In E. Milne-Redhead and R.M. Polhill (Eds.) *Flora of Tropical East Africa*. East African Community.

Cory H and Hartnoll M.M. (1945). Customary *law of the Haya tribe, Tanganyika territory*. Frank Cass & Co, London.

Deininger K and Jin S. (2006). Tenure security and land-related investment: Evidence from Ethiopia. *European Economic Review* 50, 1245-1277.

Deugd, M. (1994). Estimation of nutrient fluxes in the Bukoban agro ecosystem. Method development for data collections to assess sustainability on field level in Tanzania. MSc Thesis; Department of Agronomy, Agricultural University Wageningen, The Netherlands. 45pp.

Durvernoy, I. (2000). Use of a land cover model to identify farm types in the Misiones agrarian frontier (Argentina). *Agricultural Systems* 64**,** 137-149.

Ehui, S., and Pender J. (2005). Resource degradation, low agricultural productivity, and poverty in sub-Saharan Africa: pathways out of the spiral. *Agricultural economics* 32: (1) 225-242.

Eijk, J. van der. (1995). Nutrient losses via leaching in Bukoba District. MSc Thesis, Department of Soil Science and Plant Nutrition, Wageningen Agricultural University, Netherlands.

ESRF. (2006). Trade and Poverty in Tanzania: Missing Impacts or Linkages? A Background Paper for Tanzania's Case Study of the CUTS's. Project on Trade, Development and Poverty (TDP), pp. 30.

Emtage N, Suh J. (2005). Variations in socioeconomic characteristics, farming assets and livelihood systems of Leyte rural households. *Annals of Tropical Research* 27: 35-54.

Evans A.C, Mitchell H.W. (1961). Soil fertility studies in Tanganyika. I. Improvement to crop and grass production on leached sandy soils in Bukoba. *East Africa Agriculture and Forest Journal* 27: 189-197.

Field, C.R., Simpkin, S.P. (1985) The importance of camels to subsistence pastoralists in Kenya. IPAL technical report E-7, UNESCO, Nairobi, 161-192pp.

Frantkin, E., Roth E.A. (1990). Drought and Economic Differentiation Among Ariaal Pastoralists of Kenya. *Human Ecology* 18: (4) 385-402.

Friedrich, K.H (1968) ‘Coffee-banana holdings at Bukoba: the reasons of stagnation at a higher level’, In: Ruthenberg H (ed.): Smallholder farming and smallholder development in Tanzania, the ten case studies. IFO Africa-Stud. No 24, Munchen. 175-212.

Færge J, Magid J. (2004). Evaluating NUTMON nutrient balancing in Sub-Saharan Africa. *Nutrient Cycling in Agroecosystems* 69: 101-110.

Forejtová J, Lád F, Třináctý J, Richter M, Gluber L, Doležal P, Homolka P, Pavelek L (2005). Comparison of organic matter digestibility determined by *in vivo* and *in vitro* methods. *Czech Journal of Animal Science* 50(2):47-53.

Fourie J.H, Engles E.A, Bruyn H.L. (1986). The influence of stocking rate and grazing system on the crude protein content and digestibility of *Tarchonarithus veld* in Nothern Cape. *Journal of Grassland Society of South Africa* 3:62-69.

FSR Project. (1990). Diagnostic Survey of Bukoba District; Formal Survey. Working paper No. 3. Tanzania Netherlands Farming System Research Project, Lake Zone. Maruku Agricultural Research Institute, Bukoba, Tanzania; Ukiriguru Agricultural Research Institute, Mwanza, Tanzania; Royal Tropical Institute, Amsterdam.

Gallegos, E.C. (2003). Improving a native pasture with a legume Arachis pintoi in the humid tropics of México. PhD Thesis. Wageningen University, The Netherlands.

Genstat® Committee (2007). Release 10.2, Feb. 2008. Lawes Agricultural Trust. Rothamsted Experimental Station.

Giller, K.E., Rowe, E.C., de Ridder, N. and van Keulen, H. (2006). Resource use dynamics and interactions in the tropics: Scaling up in space and time. *Agricultural Systems*. 88:8-27.

Giller K.E., Witter, E., Corbeels M, Tittonell. P. (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Res*. doi:10.1016/j.fcr.2009.06.017.

Gold, C.S., Karamura, E.B., Kiggundu, A., Bagamba, F., Abera, A.M.K., (1999). Monograph on geographic shifts in highland cooking banana (Musa, group AAA-EA) production in Uganda. *African Crop Science Journal*. 7, 223–298.

Grandin B. (1988). Wealth Ranking in Smallholder Communities: *A Field Manual. Intermediate Technology Publications*, Nottingham, England.

Green M, Lukanu G, Worth S, Greenfield P.L. (2006). Use of wealth ranking to analyze factors influencing smallholder farmers' market perception in the Northern Mozambique. *Development Southern Africa.* 23: 669-683.

Guinand Y (1996). A method to help select farmers for on-farm agroforestry trials, based on wealth ranking. AFRENA Report No. 102, International Centre for Research in Agroforestry, Nairobi, Kenya.

Harvey C. (1938). Notes on *Rweya* land cultivation. In: Maruku Station Book Notes, 1920-60. Notes on various topics, Unpublished. Nyakato Agricultural Research Station and Maruku Coffee Station, Bukoba, Tanzania.

Haugerud A (1989). Land tenure and agrarian change in Kenya, Africa 59: 61-90.

Heady H.F. (1960). *Range management in East Africa*. Government printer, Nairobi.

Herrero M, González-Estrada, E, Thornton P.K, Quirós C, Waithaka M.M, Ruiz R, Hoogenboom G. (2007). IMPACT: Generic household level databases and diagnostics tools for integrated crop-livestock systems analysis. *Agricultural Systems.* 92: 141-157.

Herrero M, González-Estrada E, Thornton P.K, Hoogenboom G. (2005). IMPACT: *Integrated Modeling Platform for Animal – Crop systems*. In: Kirby, D.K., Quirós, C (eds.) Users manual version 1.1. International Livestock Research Institute, Nairobi, Kenya.

Houérou, H.N. Le and Hoste, C.H. (1977). Rangeland production and annual rainfall relations in the Mediterranean Basin and in the African Sahelo-Sudanian zone. *Journal of Range Management*. 30 (3). 181-189

Iliffe J. (1979). *A modern History of Tanganyika*. Cambridge University Press.

INIBAP, (1990). "Annual Report for 1989. International Network for the Improvement of Banana and plantain." Montpelier.

Ittersum, M.K, van., and Rabbinge, R. (1997). Concepts in production ecology for the analysis and quantification of agricultural input-output combinations. *Field Crops Research.* 52, 197-208.

Janssen, B.H. (1993). Report on consultancy mission to the Lake Zone Farming System Research Project on behalf of the Bukoba nutrient balance study. Dept. Soil Science and Plant Nutrition, WAU.

Janssen, B.H., Guiking, F.C.T., van der Eijk, D., Smaling, E.M.A., Wolf, J., Reuler, H. (1990). A system for quantitative evaluation of the fertility of tropical soils. *Geoderma.* 46, 299-318.

Jodha, N.S. (1986). Common Property Resources and Rural Poor in Dry Regions of India. *Economic and Political Weekly*. 21(27):1169-1181.

Kabatange, A.M. and Shayo, C.M. (1997). Rumen degradation of maize stover as influenced by Leucaena hay supplementation. [http://www.cipav.org.co/Irrd/Irrd3/2/sarec1.htm] Site visited on 15/09/2011.

Kaihura F.B.S, Rugangira D.M. (2003). Technical and policy recommendations for sustainable management of agricultural biodiversity: Recommendations for Tanzania with contributions from meeting participants. In: Kaihura F, Stocking M (eds.) Agricultural Biodiversity in Smallholder farms of East Africa. United Nations University, Accra, Ghana.

Kalikawe T.S. (1974). The *Nyarubanja* land tenure system and its impact on the growth of coffee in Bukoba. BA Dissertation, University of Dar es Salaam, Tanzania.

KCDP Banana Project. 2000. Project document. BTC/PMO/MoA. Dar es salaam.

Kop P.J van de. (1995). The role of cattle in nutrient fluxes of the banana-based agro-ecosystem of Bukoba District, Tanzania. MSc Dissertation, Department of Agronomy, Department of Soil Science and Plant Nutrition, Wageningen Agricultural University, Wageningen.

Kitessa S, Flinn P.C, Irish G.G. (1999). Comparison of methods used to predict the *in vivo* digestibility of feeds in ruminants. *Australian Journal of Agricultural Research*. 50(5):825-841.

Langlands, B.W. (1967). Burning in East Africa. *East Africa Geography Review*. 5:21-37.

Lal P, Lim-Applegate H, Scoccimarro M. (2001). The adaptive decision-making process as a tool for integrated natural resource management: focus, attitudes, and approach. *Conservation Ecology*. 5(2):11.

Leng, R.A. (1990). Factors affecting the utilization of ‘‘poor quality’’ forage by ruminants particularly under tropical conditions. Nutrition Research Reviews 3: 277-303.

Lesorogol C.K. (2005). Privatizing Pastoral Lands: Economic and Normative Outcomes in Kenya. *World Development*. 33(11): 1959–1978.

Lorkeers A.R, Tegamaisho R, van de Kop P.J. (1996). *Rweya* soils, grasses, and *Rweya* use for cattle production’. Applied soil fertility project. Unpublished project report, ARI Maruku, Bukoba, Tanzania (mimeo). [http://www.ecologyandsociety.org/vol5/iss2/art11/] Site visited on 19/10/2012.

Lorkeers A. (1995). Agro-ecological zones of Bukoba District Tanzania. Bukoba District Council, Bukoba District Rural Development Programme. Applied Soil Fertility Project, Soil Section, ARI Maruku, Bukoba, Tanzania.

Magina, F.L. (2005). A review of coffee pest management. TACRI. [http://www.aaec.vt.edu/ipmcrspuganda/IPMCRSPEA/Publications/Current_Research_Profiles/Coffee_Current_Research_Profiles/Tanzania_Coffee_research_profile.pdf] Site visited on 20/05/2013

MALD. (1984). Tanzania livestock census (provisional report). Ministry of Agriculture and Livestock Development, Dar es Salaam, Tanzania.

Maruo S. (2002). Differentiation of subsistence farming patterns among the Haya banana growers in north-western Tanzania. *African Study Monographs.* 23: 147-175.

Mbwana A.S.S, Mgenzi, S.R.B, Steenhuijsen Piters B. de and Baijukya, F.P, (1983). “Banana Recommentations and Research Needs in Kagera Region.” Field Note no.70. Tanzania.

Mbwana A.S.S, Mgenzi S.R.B, Steenhuijsen Piters Bde, Baijukya F.P. (1997) .Banana Recommendations and Research Needs in Kagera Region. Field Note no.70. Maruku Agricultural Research Institute, Bukoba, Tanzania.

McDonald P, Edwards R.A, Greenhalgh J.F.D. (1981). *Animal nutrition*. Longman, Harlow/New York.

McNaughton S.J. (1979). Grassland-herbivore dynamics, in Serengeti. In E. Rodenwalt and H.J. Jusatz (Eds.). *Dynamics of an Ecosystem*. University of Chicago Press, Chicago.

Migot-Adholla S, Hazell P, Blarel B and Place F. (1991). Indigenous land rights systems in Sub-Saharan Africa: A constraint on productivity?, *World Bank Economic Review*. (2): 155-175.

Milne G. (1938). Essays in applied pedology III. Bukoba: High and low fertility on a laterised soil. *East African Agricultural and Forestry Journal.* 4:13-24.

Mlay P.S. Pereka A.E. Balthazary S.T. Phiri E.C.J. Hvelplund T. Weisbjerg M.R. Madsen Jørgen. (2006). The effect of maize bran or maize bran mixed with sunflower cake on the performance of smallholder dairy cows in urban and peri-urban area in Morogoro, Tanzania. *Livestock Research for Rural Development*. 17 (1), 1-11.

Mutahaba G. (1969). The Importance of Peasant Consciousness for Effective Land Tenure Reform: The Problem of Abolishing *Nyarubanja* Land Tenure in Bukoba District. Undergraduate Dissertation, University of Dar es Salaam, Tanzania.

Mwangi, W.M. (1997). Low use of fertilizers and low productivity in Sub-Saharan Africa. *Nutrient Cycling in Agroecosystems.* 47: 135-147.

Mwanukuzi, P.K. (2009). Impact of eucalyptus and pine growing on rural livelihoods: the lesson from Bukoba area, north western Tanzania. *African Journal of Ecology*. 47(1): 105-109.

Mwijage A.N, Ridder Nde, Baijukya F, Pacini C and Giller K.E. (2009)**.** Exploring the variability among smallholder farms in the banana-based farming systems in Bukoba District, Northwest Tanzania. *African Journal of Agricultural Research*. 4(12): 1410-1426.

Mwijage A, Andersson, J, Ridder Nde, Baijukya F, Pacini C and Giller K. (2011)**.** **"**Impact of Land Tenure Change on Subsistence agriculture: Implication on Farm productivity on the farming system in Bukoba District, Tanzania."*Journal of African Studies and Development*, Vol. 3(3), pp. 33-44.

Mwilawa A.J, Komwihangilo D.M., Kusekwa M.L. (2008). Conservation of forage resources for increasing livestock production in traditional forage reserves in Tanzania. *African Journal of Ecology*. 46: 85-89.

Mwita, C. (2003). Productivity and nutrition value of *Kikamba* grass and legume forages in Bukoba District, Tanzania. MSc Thesis, Department of Animal Science and Production, Sokoine University of Agriculture, Tanzania.

National Bureau of Statistics (NBS) (2002) Population and housing census, Kagera Region, Tanzania. [http://www.tanzania.go.tz/census/Districts/bukobarural.htm] Site visited on 25/03/2012.

National Bureau of Statistics (NBS) and office of Chief Government Statistician OCGS), Zanzibar (2013). *The 2012 population and housing census: Population Distribution by Administrative units. Key findings*. Dar es Salaam, Tanzania: NBS and OCGS.

NEI. (1994). Coffee Sector Study report Kagera Region Tanzania. Netherlands Economic Institute, ZED and HVA International, Roterdam, The Netherlands.

Nichols J.D, Rosemeyer M.E, Carpenter F.L, Kettler J. (2001). Intercropping legume trees with native timber trees rapidly restores cover to eroded tropical pasture without fertilization. *Forest ecology and Management*. 152:195-209.

Nkuba, J.M. (1997). The diversity of the Bukoba farming system and its household typology, Kagera region, Tanzania. MSc dissertation. The University of Queensland, Australia.

Nkuba, J.M., R.R.B. Mgenzi., M. Ishika., and C. Mushongi. (2003). Evaluationg the marketing opportunities for banana and its products in the principle banana growing countries of ASARECA, Case study of Tanzania. Bukoba, Tanzania: Maruku Agricultural Research and Development Institute.

Nsahlai I.V, Umunna N.N. (1996). Sesbania and Lablab supplementation of Oat hay basal fed to sheep with or without maize grain. *Animal Feed Science and Technology*. 61:275-279.

Nyerere J.K. (1967). *Ujamaa Essays on Socialism*. Oxford University Press. Dar es Salaam.

Nyombi, K., (2010). *Understanding growth of East Africa highland banana: experiments and simulation.* PhD Thesis, Wageningen University, Wageningen, The Netherlands.

Nyombi, K. van Asten, P.J.A. Leffelaar, P.A. Corbeels, M. Kaizzi, C.K. Giller, K.E. (2009). Allometric growth relationships of East Africa highland bananas (*Musa* spp., AAAEAHB) cv. Kisansa and Mbwazirume. *Annals of Applied Biology*. *155*, 403−418.

Otte M.J. and Chilonda, P. (2002). Cattle and small ruminant production systems in sub-Saharan Africa: A systematic review. FAO

Page A.L, Miller R.H, Keeney D.R (Eds.). (1982). *Methods of Soil Analysis, Part 2. Soil and Microbiological Properties 2nd Edition.* American Society of Agronomy, Madison, Wisconsin, USA.

Palm C.A., Myers, R.J.K., Nandwa, S.M. (1997). Combined Use of Organic and Inorganic Nutrient Sources for Soil Fertility Maintenance and Replenishment. In: Replenishing Soil Fertility in Africa. Special Publication Number 51. R.J. Buresh, P.A. Sanchez, and F. Calhoun (Eds.). *Soil Science Society of America* American Society of Agronomy Madison, Wisconsin, USA. [http://soil5813.okstate.edu/Africa/Replenishing_soil_fertility_in_africa.pdf#page=206] Site visited on 15/08/2012.

Peters, P.E (2009). Challenges in Land Tenure and Land Reform in Africa: Anthlopopogical Contributions. *World Development.* 37(8):1317 – 1325.

Pereira H.C, Jones P.A. (1954). Field responses by Kenya coffee to fertilizers, manure and mulches. *Empire Journal of Experimental Agriculture*. 22:23-36.

Platteau J. (1996). The Evolutionary Theory of Land Rights as Applied to Sub-Saharan Africa: A Critical Assessment. *Development and Change.* 27(1): 29-86.

Pokorny D (1973). The Haya and their land tenures: property rights and the surplus problem. *Rural Africa*. 22: 93-123.

Pratt D, Gwynne, M. (1977). *Rangeland management and Ecology in East Africa*. Hodder and Stoughton, London.

Prachett D, Capper B.G, Light D.E Miller M.D, Rutherford A.S, Rennie T.W, Buck N.G, Trail J.C. (1977). Factors limiting liveweight gain of beef cattle on rangeland in Botswana. *Journal of Range Management*. 30:442-445.

Rald J, Rald K. (1975). *Rural organization in Bukoba District, Tanzania*. København, Uppsala, Sweden.

Ray, D. (1998). *Development economics*. Princeton University Press, Princeton, New Jersey.

Reining P.C. (1967). The Haya: *The Agrarian System of a Sedentary People*. Ph.D Thesis. University of Chicago. U.S.A.

Ridder Nde, Breman H. (1993). A new Approach to Evaluating Rangeland Productivity in Sahelian Countries. In: Behnke, R.H. Jr., Scoones. I and Kerven, C. (Eds.). *Rangeland ecology at Disequilibrium; New models of natural variability and Pastoral adaptation in African Savannas*. p 104-117. ODI.

Roetter, R.P. and van Keulen, H. (2007). Food security. In: R.P. Roetter, H. van Keulen, M. Kuiper, J. Verhagen. And H.H. van Laar (Eds.) *Science for Agriculture and Rural Development in low income countries*. Springer, Netherlands. Pp.27-56.

Rufino M, Rowe E.C, Delve R.J, Giller K.E. (2006). Nitrogen Cycling Efficiencies Through Resource-poor African Crop-livestock systems. *Agriculture, Ecosystems and Environment.* 112:261-282.

Rugalema, G.H., Johnsen, F.H., Rugambisa, J. (1994). The homegarden agroforestry system of Bukoba District, North-Western Tanzania. 2. Constraints to farm productivity. *Agroforestry Systems*. 26: 205-214.

Rutherford, M.A. and Phiri. N (2006). Pests and Diseases of Coffee in Eastern Africa: a Technical and Advisory Manual. CABI, Ascot and Nairobi. 70pp.

Sanchez, P.A. and Leakey, R.B. (1996). Land use transformation in Africa. Three determinants for balancing food security with natural resources utilization. Paper presented at the 4th Congress of the European Society of Agronomy, The Hague, 7-11 July.

Savadogo M. (2000). *Crop residue management in relation to sustainable land use. A case study in Burkina Faso.* Ph.D. Thesis Wageningen Agricultural University, Wageningen. The Netherlands.

Schenk ,M. K and Barber S. A. (1980). Potassium and phosphorus uptake by corn genotypes grown in the field as influenced by root characteristics. *Plant and Soil.* 54 (65-76).

Shackleton C.M and Mentis, M.T. 1992. Seasonal changes in nutrient content under three defoliation treatments in two coastal grassland communities of Transkei. Journal of Grassland Society of South Africa 9:30-37.

Sharrock G.O.G, Waldie K.J, Yoshi Y.R. (1993). A wealth ranking for agricultural research purposes in the eastern hills of Nepal. RRA Notes No. 18, International Institute for Environment and Development, London.

Shand, M. (2006), Administrative Divisions. At: [http://web.ges.gla.ac.uk/%7Emshand/kagera/ADMIN.GIF] Site visited on 12/4/2012.

Shephered, K.D., Ndufa, J.K., Ohlsson, E., Sjogren, H. and Swinkles, R., (1997). Adoption potential of hedgerow intercropping in maie-based cropping systems in the highlands of western Kenya. I. Background and agronomic evaluation. *Experimental Agriculture*. 33: 197-223.

Simmonds, N.W. (1966). *Bananas*, 2nd edn. Longman. London.

Stéphenne, N, Lambin, E.F. (2001). A dynamic simulation model of land-use changes in Sudano-sahelian countries of Africa (SALU). *Agricultural Economics and Environment*. 85: 145-161pp.

Smaling, E.M.A, Janssen, B.H (1997). Calibration of QUEFTS, a model predicting nutrient uptake and yields from chemical soil fertility indices. Geoderma 59, 21-44.Smith C.D (1984). Sustainable development reconsidered: rich farmers of Kagera region in Tanzania. *Labour, Capital and Society*. 27: 34-54.

Smith R.E. (2004). Land Tenure, Fixed Investment, and Farm Productivity: Evidence from Zambia's Southern Province. *World Development*. 32(10): 1641-1661.

Steenhuijsen Piters B de. (1999). A concise History of Land Use in Kagera Region, Tanzania', in Folmer ECR, Schouten C and Baijukya FP (eds) Planning the Future: Past, Present and Future Perspectives of Land Use in the Kagera Region, Tanzania. Report for the 50th anniversary of ARI Maruku. LZARDI, Maruku, Tanzania.

Singh J.S, Lauenroth W.K, Steinhurst R.K. (1975). Review and assessment of various techniques for estimating net aerial primary production in grasslands from harvest data. *Botanical Reviews*. 41:181-232.

Skerman P.J, Riveros F. (1990). *Tropical grasses*. FAO. Rome.

Tibaijuka A.K. (1984). An Economic Analysis of Smallholder Banana-Coffee Farms in the Kagera Region, Tanzania: Causes of the Decline in Productivity and Strategies for Revitalization. PhD dissertation, Swedish University of Agricultural Sciences, Uppsala.

Tilley J.M.A, Terry R.A. (1963). A two stage technique for the *in vitro* digestion of forage crops. *Journal of the British Grassland Society*. 18:104-111.

Tittonell, P.A. (2008). Msimu wa Kupanda. Targeting resources within diverse, heterogeneous and dynamic farming systems of East Africa. PhD Thesis Wageningen University, pp. 320.

Tittonnel, P., Vanlauwe, B., Leffelaar, P.A., Shepherd K.D. and Giller K.E. (2005). Exploring diversity in soil fertility management of smallholder farms in western Kenya. Ii. Within-farm variability in resource allocation, nutrient flows and soil fertility status. *Agriculture, Ecosystems and Environment.* 110, 166-184.

Tittonell P, Vanlauwe, B, Ridder N de, Giller K.E. (2007). Heterogeneity of crop productivity and resource use efficiency within smallholder Kenyan farms: soil fertility gradients or management intensity gradients? *Agricultural Systems*. 94: 376-390.

Tittonell P. Muriuki, A, Shepherd, K.D,. Mugendi, D, Kaizzi , K.C. Okeyo J, Verchot, L, Coe R. Vanlauwe, B. (2010).The diversity of rural livelihoods and their influence on soil fertility in agricultural systems of East Africa – A typology of smallholder farms. *Agricultural Systems.* 103 (2010) 83–97.

Toulmin C. (2008). Securing land and property rights in sub-Saharan Africa: The role of local institutions. *Land Use Policy*. 26: 10–19.

Touber L, Kanani J.R. (1994). Land forms and soils of Bukoba District. Bukoba District Council, Bukoba District Rural Development Programme. Applied Soil Fertility Research Project, Soil Section, ARI Maruku, Bukoba, Tanzania.

Tueller P.T, Tower J.D. (1979). Vegetation stagnation in three phase big game enclosures. *Journal of Range Management*. 32:258-263.

UNAIDS. (2008). *Report on the global AIDS epidemic*. UNAIDS, Switzerland, pp. 361.

URT. (1994) Report of the presidential Commission of Inquiry into Land Matters, Vol. 1: Land Policy and Land tenure structure'. Ministry of lands, Housing and Urban development, Dar es Salaam, Tanzania in cooperation with the Scandinavian Institute of African Studies, Uppsala, Sweden.

Vesey-Fitzgerald D. (1973). *East African Grasslands*. PPC Ltd, Nairobi.

De Weerdt, J (2003). "Risk sharing and endogenous network formation. Discussion paper,"Mimeo, DP2002/57, WIDER, United Nations University.

Winston, A.C., Littlemore, J., Scudamore-Smith, P., O'Farrell, P.J., and Doogan, V.J. (1992). Effect of Nitrogen and potassium on growth and yield of coffee (Coffea Arabica L.) in tropical Queensland. *Australian Journal of Experimental Agriculture*. 32, 217-224.

World Bank. (1974). *Land reform*. World Bank Development Series. Wasington D.C. The World Bank.

Wijnalda D. (1996). Soil fertility, productivity and Nutrient Balances of Different Land Use Types in Bukoba District, Tanzania. MSc Dissertation, Wageningen University, Department of Soil Science and Plant Nutrition, Wageningen, The Netherlands.

Wily L.A. (2000). Land tenure reform and the balance of power in eastern and Southern Africa. *Natural Resources Perspectives*. No 58. ODI/DFID.

Yanggen, D., V. Kelly., T. Reardon,. and Naseem. A. (1998). Incentives for fertilizer use in sub-Saharan Africa: A review of empirical evidence on fertilizer response and profitability. International Development Working Paper No. 70. [http://ageconsearch.umn.edu] Site visited on9/3/2008.

Zingore S. (2006). Exploring diversity within smallholder farming systems in Zimbabwe. Nutrient use efficiencies and resource management strategies for crop production. PhD thesis, Wageningen University, The Netherlands.

Zingore S, Murwira H.K, Delve R.J, Giller K.E. (2007a). Influence of nutrient management strategies on variability of soil fertility, crop yields and nutrient balances on smallholder farms in Zimbabwe. *Agriculture, Ecosystems and Environment.* 119: 112-126.

Zingore S, Murwira H.K, Delve, R.J Giller K.E. (2007b). Soil type, historical management and current resource allocation: three dimensions regulating variability of maize yields and nutrient use efficiencies on African smallholder farms. *Field Crops Research*. 101: 296-305.

APPENDICES

Appendix 1: Selected *Kikamba* rotations by the model with respective nitrogen balance (kg rotation^{-1} ha^{-1} over four seasons for the three farm types in Bukoba District

Rotation code	Seasons				Nitrogen balances for the three farm types		
	LR1	SR1	LR2	SR2	FT1	FT2	FT3
57	Sp	M_Sp	Lmat_r	M_Lmat_r	-1.69E-14	-1.69E-14	-1.68E-14
65	Sp	M_f_Sp	We	We	-1.17E-14	-1.18E-14	-1.19E-14
100	Sp	We	We	We	9.79E-15	9.82E-15	9.87E-15
135	Sp_i	M_Sp_i	We	We	4.62E-14	4.61E-14	4.59E-14
205	Sp_i	We	We	We	1.11E-13	1.22E-13	1.34E-13
211	Sp_i	We	Sp_i	We	-0.6	-0.6	-0.6
214	Sp_i	We	Lm_m	M_Lm_m	-3.34E-14	-3.35E-14	-3.37E-14
222	Sp_i	We	Ltc_r	We	1.20E-12	1.20E-12	1.20E-12
230	Sp_i	We	Lma_r	We	-3.33E-19	-3.33E-19	-3.33E-19
231	Sp_i	We	Lma_r	Lma_r	1.89E-18	1.89E-18	1.89E-18
276	Lm_r	M_Lm_r	Lm_r	M_Lm_r	-1.34E-14	-1.28E-14	-1.21E-14
279	Lm_r	We	Sp	M_Sp	9.78E-15	9.75E-15	9.72E-15
293	Lm_r	Lm_r	Sp_i	We	-1.04E-14	-9.97E-15	-9.43E-15
295	Lm_r	Lm_r	Lm_r	We	1.35E-14	1.30E-14	1.23E-14
406	Lma_r	Lma_r	Sp_i	We	1.89E-18	1.89E-18	1.89E-18
410	Lmat_r	M_Lmat_	Sp	M_Sp	-8.51E-14	-8.51E-14	-8.51E-14
417	Lmat_r	M_Lmat_	Lmat_r	We	2.02E-14	2.02E-14	2.02E-14
425	Lmat_r	We	Lmat_r	M_Lmat_r	8.61E-14	8.61E-14	8.61E-14
429	Lmat_r	Lmat_r	Sp	M_f_Sp	9.90E-14	9.91E-14	9.92E-14
435	Lmat_r	Lmat_r	Lmat_r	We	-1.15E-13	-1.15E-13	-1.15E-13

M -maize
M_Sp -Maize after sweet potato
M_f_Sp - fertilized maize after sweet potato
M_Sp_i - maize after incorporated sp residues
M_f_Sp_i –fertilized maize after incorporated sp residues
M_f - maize fertilized
M_Lm_i - maize after incorporated *Mucuna* residues
M_Lm_m - maize after mulched *Mucuna* residues
M_Lm_r - maize after removed *Mucuna* residues
M_Ltc_i - maize after incorporated *Tephrosia* residues
M_Ltc_r - maize after removed *Tephrosia* residues
M_Lcg_i - maize after incorporated *Clotaralia* residues
M_Lcg_r - maize after removed *Clotaralia* residues
M_Lma_r - maize after removed *M. axillare*
M_Lmat_r - maize after removed *atropurpureum*

Lm_i – legume *Mucuna* incorporated
Lm_m - legume *Mucuna* mulched
Lm_r - legume *Mucuna* removed
Ltc_i - legume *Tephrosia* incorporated
Ltc_r - legume *Tephrosia* removed
Lcg_i - legume *Grahamiana* incorporated
Lcg_r - legume *Grahamiana* removed
Lma_r - Legume *M. axillare* removed
Lmat_r - Legume *atropurpureum* removed
Ld_r - Legume *Desmodium* removed
We - weed
Sp - sweet potato
Sp_i - sp incorporated

Appendix 2: Selected *Kikamba* rotations and associated N-balance for the farming households with cattle grazing in the *Rweya* in Bukoba District

Rotation code	LR1	SR1	LR2	SR2	*Kikamba* N balance
79	Sp	M_f_Sp	Ltc_i	M_Ltc_i	5.25E-15
106	Sp	We	Sp_i	We	-2.78E-16
208	Sp_i	We	Sp	We	1.01E-14
211	Sp_i	We	Sp_i	We	-0.6
212	Sp_i	We	Lm_i	M_Lm_i	1.17E-15
224	Sp_i	We	Lcg_i	M_Lcg_i	1.57E-15
230	Sp_i	We	Lma_r	We	-3.33E-19
231	Sp_i	We	Lma_r	Lma_r	1.89E-18
254	Lm_m	M_Lm_m	Sp	M_Sp	1.64E-15
255	Lm_m	M_Lm_m	Sp	M_f_Sp	2.22E-16
270	Lm_r	M_Lm_r	Sp	M_Sp	1.77E-16
287	Lm_r	We	Lm_r	Lm_r	-2.01E-16
293	Lm_r	Lm_r	Sp_i	We	-1.55E-16
296	Lm_r	Lm_r	Lm_r	Lm_r	2.68E-16
322	Ltc_r	We	Sp	M_Sp	-4.36E-15
367	Lcg_r	We	Sp	We	-1.76E-16
406	Lma_r	Lma_r	Sp_i	We	1.89E-18