Problems and opportunities of wetland management in Rwanda

Nsharwasi Léon Nabahungu

Thesis committee

Thesis supervisor
Prof. dr. ir. L. Stroosnijder
Professor of Land Degradation and Development
Wageningen University

Thesis co-supervisor
Dr. S. M. Visser
Teamleader, Alterra, Wageningen UR

Other members
Prof. dr. H.H.T. Prins, Wageningen University
Prof. dr. K.E. Giller, Wageningen University
Dr. ir. G.E. Halsema, Wageningen University
Dr. B. Vanlauwe, CIAT-Nairobi TSBF, Kenya

This research was conducted under the auspices of Graduate School: C.T. de Wit Production Ecology and Resource Conservation

Problems and opportunities of wetland management in Rwanda

Nsharwasi Léon Nabahungu

Thesis
submitted in fulfilment of the requirements for the degree of doctor
at Wageningen University
by the authority of the Rector Magnificus
Prof. dr. M.J. Kropff,
in the presence of the
Thesis Committee appointed by the Academic Board
to be defended in public
on Tuesday 10 April, 2012
at 4 p.m. in the Aula.

Nsharwasi Léon Nabahungu
Problems and opportunities of wetland management in Rwanda, 134 pages.

Thesis Wageningen University, the Netherlands (2012)
With references, with summaries in English and Dutch

ISBN 978-90-8585-924-6

Financially supported by
Netherlands Fellowship Programme (NFP)
Land Degradation & Development (LDD) Group of Wageningen University

Acknowledgements

The completion of this work has been possible through the assistance and co-operation of several people and institutions. I am grateful to Netherlands Fellowship Programme (NFP), the Land Degradation & Development (LDD) Group of Wageningen University and CIALCA for the PhD sandwich fellowship, which allowed me to stay in Wageningen and to support my field and laboratory activities. A special thanks to my promoter Prof. Dr. ir. Leo Stroosnijder (Chair of Land Degradation and Development Group) who accepted me as a PhD student and assisted throughout this thesis. Many thanks to my daily supervisor Dr. Saskia M. Visser; your comments, field trips to Rwanda, moral support, encouragement and stimulating discussions have guided me all over the current thesis. I am deeply indebted to my supervisor in Rwanda Dr. Bernard Vanlauwe. Thanks for your scientific guidance during on-farm experiments and papers writing in spite of your many other duties. To Dr. J.G Mowo, World Agroforestry Centre coordinator of Eastern African region, thanks for your contribution to improve the quality of this dissertation.

I am very grateful to the entire academic, technical and administrative staff members and PhD students of the LDD group. I really enjoyed the lovely working environment and nice social events with them, all of which I can never forget. My special words of thanks go to Dirk Meindertsma and Marnella van der Tol for organizing my repeated travels to and from Wageningen and arranging for my accommodation.

I would like to express my gratitude to my home institute ISAR for selecting me as candidate for PhD studies and for granting me time to do the research. I wish to thank my colleagues at Ruhande station, all of them have contributed to this work in one way or another. Special thanks go to Kabiligi Michel, Ngenzi Guy and Mbanda Jocelyne for excellent field work and survey.

I am highly indebted to all of you who assisted our family when my lovely Vestine was very sick. Clemence, Bernadet, Yvettes, Desiree and others, I cannot forget the nights passed at the hospital without sleeping for caring my wife and many friends and relatives to comfort us during this dark period. I thank you indeed. To my friend family Anecto Kayitare for your advices and regularly visiting my family while I stayed away or when Vestine had health problems.

I would also like to express my most sincere gratitude to my elder sister Judith M., her husband Janssen T. and their family for the love they gave to me. Janssen, your love and encouragement to undertake further studies have made me a good scientist. Please accept my sincere appreciation. I am highly indebted to my Mum, C. Nyiramutumwa who showed me parental love and installed in me values of dignity, hard work and honesty. To my father, L. Ntikanga for his continued reassurance and fatherly love.

Finally, I wish to express my sincere indebtedness to my lovely wife, V. Mukashema, and my kids R. Shema, C. Ishimwe, L. Hirwa and L. Teta for approving doing my PhD by foregoing the right to be cared by a husband and father. It is a delight for me to dedicate this work to them.

Table of Contents

Chapter 1

Introduction

Introduction

Rwanda is currently suffering from tremendous pressure on agricultural land due to the rapid demographic growth and the limited availability of productive land. The rural population density has grown from 121 persons km^{-2} in the 60's, to 262 in 1990, and to 380 persons km^{-2} in 2010 (National Statistics Institute of Rwanda, 2007). Considering that 90% of the working population in Rwanda is employed in agriculture, the per capita availability of agricultural land has declined over the decades from 3 ha per household in the 1960's to less than 1 ha per household at present (Verdoodt and van Ranst, 2006). The increasing population pressure on available land and water resources has led to their degradation, and resulted in the loss of productivity of arable lands and increased food insecurity (Bidogeza et al., 2009). Due to soil erosion processes and limited fertilizer use, the productivity of the small agricultural plots is no longer sufficient to provide food security for the majority of poor farmers (Ansoms and McKay, 2010). The response of Rwanda's farmers to the pressure on land and associated decline in productivity has been to expand their agricultural activities into the fragile wetlands.

The total area of wetlands in Rwanda is approximately 278,000 ha of which, in 2009, 53% was used for cultivation. This accounts for 12% of the total cultivated land in the country (REMA, 2009). In Rwanda "wetland" means all lowland and comprises all valley bottoms, both the well-drained and wet parts. In the past wetlands in Rwanda have been used in many different ways and in the future they have a great role to play in the national economy. Understanding the problems and opportunities regarding management of this valuable resource is vital to their long term productivity and is the focus of this thesis.

At present wetlands support the livelihoods of many poor people through agriculture providing both food and income. Most Rwandan farmers practice subsistence farming. Farmers living in the uplands make use of the neighbouring wetlands and generally plant similar crops in both up- and lowlands, except for paddy farming which is cultivated only in wetlands (Ngarambe and Kanyarukiga, 1998). In the wetlands of Rwanda, rainfed agriculture is performed in the dry areas, and groundwater dependent agriculture is practiced in the wet areas. Traditionally, farmed wetlands are simple, require low budget inputs, and cover small areas. Generally, yields in the wetlands are higher compared to yields in uplands. This is due to the continuous availability of water and the relatively higher fertility of wetlands.

The farming system and the level of organisation of farmers that cultivate the wetlands differ with the level of wetland reclamation (MINAGRI, 2002). The traditionally reclaimed wetlands are either individually or family managed, and farmers select their own crops. Sometimes, informal groups are formed in which farmers help each other with agricultural tasks in both the wetland and upland fields. At the other end of the spectrum is the situation where crops and cropping systems are selected through consensus by a management committee.

The Rwandan government considers wetlands as an important resource for the intensification of agriculture, which is required to achieve the goals of food security and poverty reduction as targeted in the agricultural policy of May 2000. According to the National Poverty Reduction Programme of the Ministry of Finance and Economic Planning, for Rwanda to achieve an overall GDP growth rate of 6.4%, agriculture should grow at 5.3%. It further estimates that improved wetland management has the potential to contribute to this growth by 0.5%. Therefore, the Rwandan government supports "wetland development" with the aim of boosting agricultural production, revitalizing the rural economy and reducing poverty (Kanyarukiga and Ngarambe, 1998).

1.1 Problem description

The government of Rwanda is keen to see that the wetlands, considered to be islands of food production, continue to play a key role in agricultural development and has allocated a substantial share of resources to their reclamation and management (Kanyarukiga and Ngarambe, 1998). Traditional management of Rwandan wetlands is based on the local knowledge of hydrology, soils and vegetation that has been gained over decades of working and observation. These practices, developed by communities, are mainly aimed at meeting the immediate needs of food and cash income with little or no consideration to their environmental consequences. Traditional systems often remain rather small scale and therefore the impact on the availability of environmental services is rather low. Large-scale new reclamations, however, have shown a number of problems.

1.1.1 Lack of awareness and recognition of the multi-functionality of wetlands at all levels

Wetland areas reclaimed by public services or under the framework of a broad project are generally large and complex and may have far reaching environmental consequences. Wetlands are valuable environmental assets and play a vital role in controlling flood waters, reducing erosion, improving water quality and serving as habitats for diverse species of plants, animals and micro-organisms (Morardet and Tchamba, 2005). Indiscriminate reclamation (destruction) of wetlands, with no consideration of their ecological functions, may result in irreversible damage to wetland ecosystems. Given the geographical position of Rwanda, almost at the heart of a dense hydrological network that constitutes the headwaters of the Nile and Congo rivers, the impacts may well extend beyond the national borders. An assessment conducted by the Rwandan government showed that the performance of the publicly reclaimed wetlands was unsatisfactory and, in many cases, has resulted in ecological and environmental damage that outweighs the value of the agricultural output from these wetlands (MINAGRI, 2002).

1.1.2 Insufficient stakeholder participation in the decision process of wetland development

While in the traditional management of wetlands only farmers were involved, large scale changes in wetland use involve many stakeholders from different levels of society. Decisions regarding wetland use should be respected at these various levels. For adoption and implementation of changes by farmers, acceptance at the farm level is crucial. Farmers tend to adopt (and adapt) if the changes are not too risky and are economically viable. Those who derive their livelihood directly from wetlands have good knowledge about the value of the water supply, craft material and dry season harvest provided by wetlands. Ignoring or excluding this knowledge in the decision making process will reduce acceptance and can lead to degradation of wetlands.

1.1.3 Lack of help with social changes for farmers

Large scale reclamation of wetlands has important social consequences as well. The farmers are required to organise themselves in associations or cooperatives directed by a wetland management committee, and crops and cropping systems are selected through consensus by both the manager of agriculture in the district and the management committee. This is a major change from the traditional manner of operating and using wetlands. In addition, existing reports (Denny and Turyatunga, 1992; Lema, 1996; MINAGRI, 2002) indicate that these intensively managed wetlands have proved to be less sustainable in crop production compared to traditionally managed wetlands. This can further bias farmers' views toward these projects, especially if there is no support for making the changes.

1.1.4 Lack of knowledge on how to intensify agricultural use of wetlands

Wetlands have great potential for boosting agricultural production, but not all of them can be developed economically. Large scale reclamation involves higher costs for drainage and the construction of irrigation networks and dams (MINAGRI, 2002). These costs need to be covered through agricultural intensification which in turn requires the use of new (higher yielding) varieties, fertilizer, etc. However, there is a lack of on-farm trials in wetlands with these newer technologies on which recommendations for farmers can be based.

1.1.5 The central problem is lack of an integrated approach for wetland development and management

For multiple reasons, including that the moisture-rich wetlands can be farmed year round; the major challenge in public wetland reclamation is to follow an integrated approach in order to achieve economically viable and environmentally sustainable use. Newly developed wetlands must be managed skilfully to achieve economic benefit while preserving the habitat and hydrological functions which wetlands provide, and which are of such great importance to long-term environmental stability. As obvious as this is, at present such an integrated and sustainable approach does not exist in Rwanda. Qualitative and quantitative information on past, current and potential use of wetland resources and the impact these have on various functions of wetlands is lacking and is an essential pre-requisite to understanding how intensive but sustainable management of wetlands can be achieved for the long-term benefit of the people of Rwanda.

This thesis, for the first time in Rwanda, applies a multi-disciplinary combination of technology, direct farmer interaction, socio-economic analysis and ground truthing approaches to generate knowledge that is vital for a systematic, informed and integrated approach to wetland development and management.

1.2 Research questions and hypothesis

Effective and sustainable wetland management can, and must, be organised from a range of integrated scales. At the national level the policy-makers in the agricultural and water resources sectors are powerful stakeholders in the wetland management debate. These policy makers need a good overview of functions, problems and opportunities of wetlands to be able to make sound decisions on further reclamation of wetlands in Rwanda. Though wetlands are the primary focus of this research, the Rwandan farming system and the biophysical processes that play a role in the wetland ecosystem make it necessary to also consider the complete watershed that lies behind the wetland in the research. Successful watershed management rests on the integration of management approaches with the livelihood goals and technical solutions with institutional interventions (Shah; 1998). It is therefore essential that any policy or approach integrates an understanding of the principles of the current farming system within the natural and social systems. Dixon and Wood (2003) proposed that integration of scientific and local (i.e. farmers') knowledge is important for reaching optimal adoption of improved management systems.

Given all these considerations it is hypothesized that an integrated watershed management approach which includes farmers' knowledge and experience about wetland uses, problems and opportunities, is key to development of strategies for sustainable wetland management in Rwanda.

To enable testing of this hypothesis, the research questions are described below.

1. What is the role of wetlands in the current smallholder farming system?
2. What problems farmers face in wetland use?
3. What opportunities for improved wetland use can be identified?

1.3 Research approach

Figure 1.1 provides an overview of the research approach. Working with the hypothesis that, if managed from a starting point of the multifunctional use, wetlands can contribute significantly to economic development, the research started at a national scale. Once existing data, including an existing watershed case study (Rugezi), had been analysed to establish currently known functions, problems and opportunities of Rwandan wetlands, the research turned to detailed work in two representative wetlands and their contributing watersheds; one in Muhanga (Rugeramigozi), Southern Province and an another in Nyagatare (Cyabayaga), Eastern province (Figure 1.2).

Given the bio-physical functions and conditions of a specific wetland, the socio-economic suitability is a reflection of both the likely magnitude of benefits to social welfare, and the extent to which existing "social conditions" are able to ensure those benefits. Therefore, to answer research question 1 we use the current contribution of wetlands to farmers' livelihood as a starting point. Combining farmers' knowledge on agricultural wetland management with scientific knowledge can lead to the development of strategies for increased productivity. The socio-economic surveys were executed at the watershed scale and the trials and nutrient flow analysis were executed at a plot scale, but at multiple locations throughout the watersheds. Eventually the research was scaled up again to the national scale to test the validity of the hypothesis that 'an integrated watershed management approach which includes farmers' knowledge and experience about wetland uses, problems and opportunities is key to development of strategies for sustainable wetland management in Rwanda.

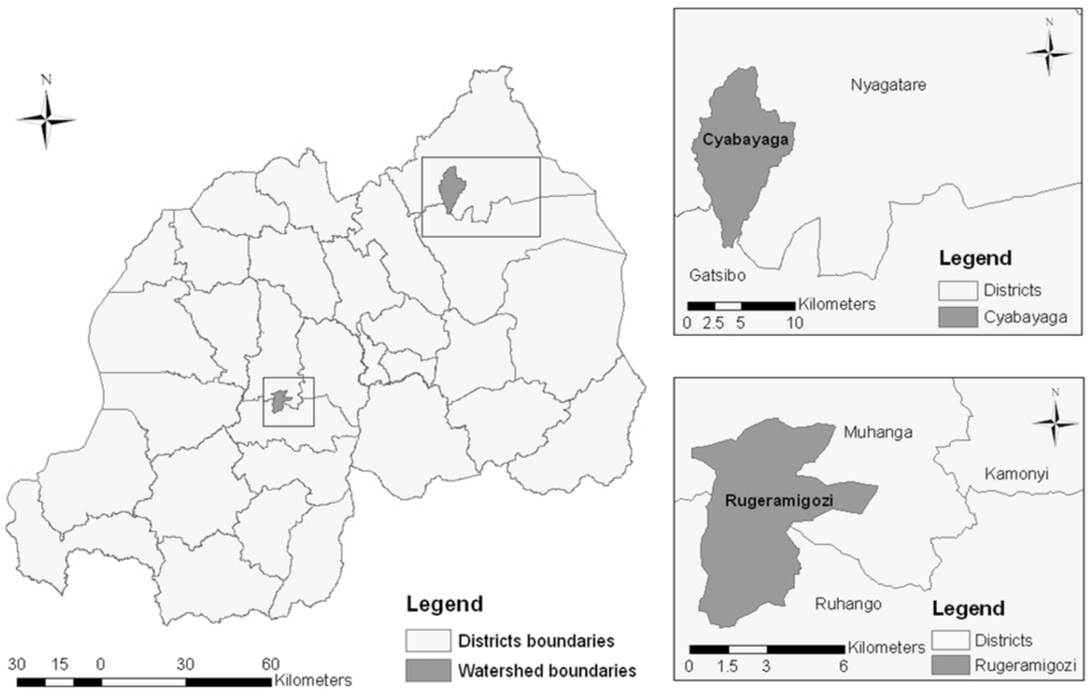


Figure 1.2. Location of Rugeramigozi, Southern Province and Cyabayaga, Eastern Province of Rwanda.

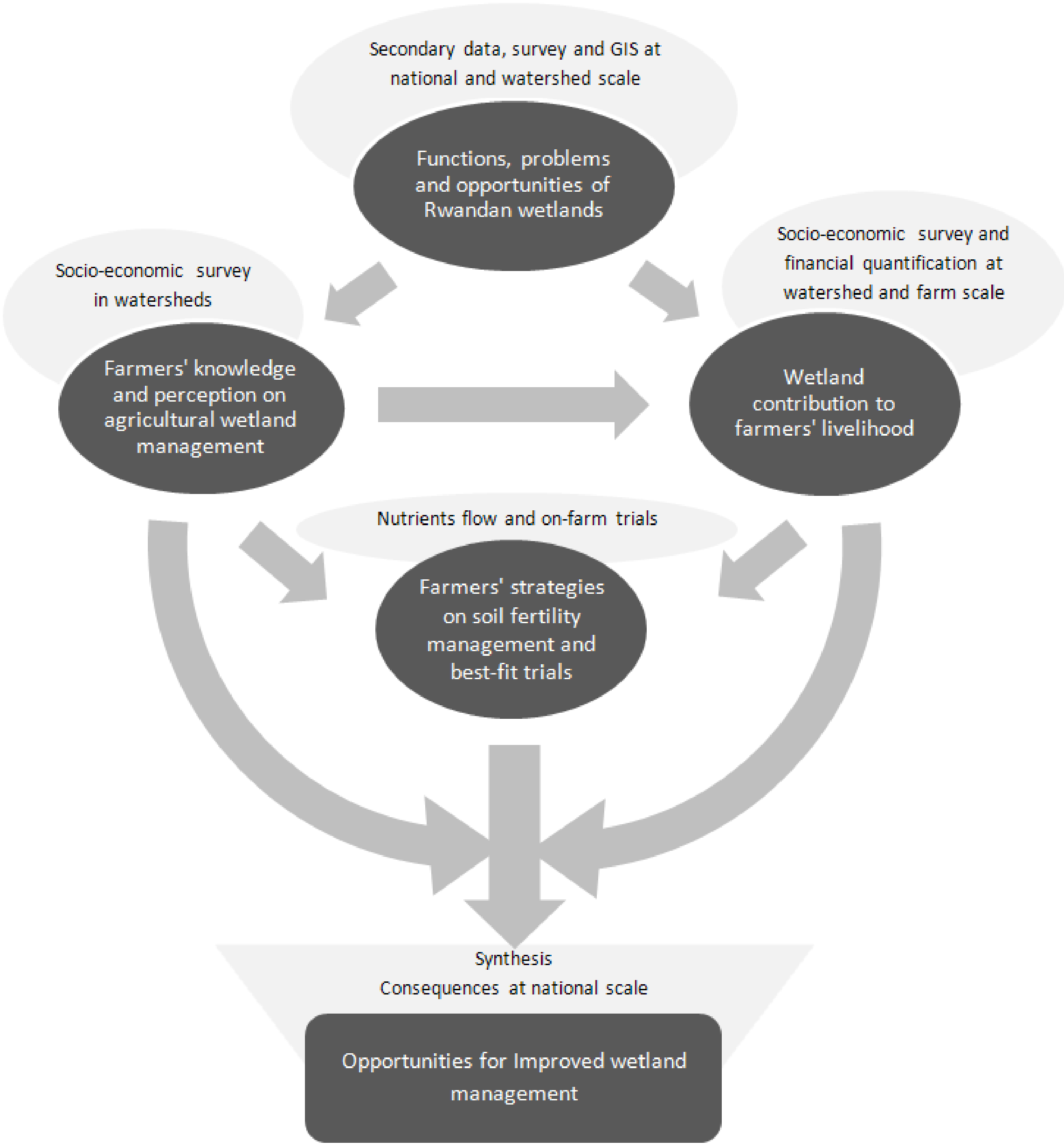


Figure 1.1. Overview of the research approach showing how the linkages between the different methodologies at different scales lead to the identification of opportunities for improved management of wetlands in Rwanda.

1.4 Theoretical framework

1.4.1 Multifunctional use of wetlands

Over the last decades there has been growing recognition throughout countries of the developed world that, rather than being unproductive wastelands, wetlands are in fact multifunctional ecosystems that provide a range of services of inherent value to human well-being (Dugan, 1990; Barbier et al., 1997; Roggeri, 1998; Silvius et al., 2000). The RAMSAR convention (Ramsar, 1971) highlights the importance of wetlands for global biodiversity, and, in recent years, research has drawn attention to the environmental functions and socio-economic benefits that wetlands can provide; what the Millennium Ecosystem Assessment (MA) (2005a) terms the “ecosystem services” of wetlands.

Figure 1.3. Wetlands as source of Papyrus, reed and biodiversity.

Discussions on the services provided by wetlands are numerous (Dugan, 1990; Roggeri, 1998; MA, 2005b), and considerable research has been carried out on specific roles wetlands play in the livelihoods of local residents and local environmental interactions (Adger and Luttrell, 2000). However, despite the wealth of literature, classifications of these services (often called functions and benefits) have rarely been consistent. Hence, the recent MA (2005a) terminology, and its widespread acceptance, is helpful. The MA uses the term "ecosystem services" for all wetland functions and benefits, and subdivides these into: "provision" (goods produced or provided by ecosystems, e.g. food, fuel and fibre); "regulate" (benefits from the processes of ecosystem regulation, e.g. water partitioning, and climate regulation); "cultural" (non-material benefits from ecosystems, e.g. spiritual, recreational and aesthetic); and "support" (factors necessary for producing ecosystem services, e.g. hydrological cycle, soil formation, and nutrient cycling). The MA ecosystem concept has received widespread recognition and has been formally adopted by the RAMSAR convention as a principal framework for wise use of wetlands (McCartney and Houghton-Carr, 2009). The first three categories of services are directly useful for or beneficial to humans or human well-being as they provide the primary means for food production, natural resources management, and spiritual beliefs. The fourth service is related to the system's capability to continue providing services through sustained natural resource process cycles. Not all wetlands support the full range of ecosystem services, and specific services may be associated with specific types of wetlands. However, the key message from this conceptualization is the linkage between different kinds of services and that support and regulating services are essential to the continuation of provisioning services (de Groot et al., 2002).

Wetland characteristics, associated in structures and processes, define the ecosystem functions that wetland can deliver. The non-renewable character of some resources (e.g. peat) or their subtractibility (water, wildlife) have the consequence that the present appropriation and use of the resource may affect its' future availability. Problems raised by wetland management can take different forms: competition among on-site direct present users (resource allocation problems), conflicts between on-site direct users and off-site indirect users and trade-offs between present and future users (intergeneration allocation problem). On-site users have an easy access to wetland resources, and can easily measure costs and benefits from services. However, for off-site indirect users it is difficult to evaluate the cost and benefits from services provided by wetlands, and in some cases they are not even aware of these services (Morardet and Tchamba, 2005).

The main functions of wetlands in Rwanda include agricultural production, hydrological regulation, biodiversity reservoir, peat reserve, and mitigation of climate change (REMA, 2008). Though the Rwandan government is keen to reclaim wetlands for agricultural production, costs of wetland reclamation should consider the multiple functions and services provided by wetlands ecosystems. The ''wise-use'' concept, advanced through the convention of wetlands (Ramsar, 1971), acknowledges that human development necessitates adjustment of wetland ecosystems, but defers from conventional natural resources management because much higher priority should be given to those processes that sustain the ecosystem and the people that depend on them (Ramsar Convention Secretariat, 2007). A key tenet of the ''wise use'' idea, also re-affirmed in the Millennium Ecosystem Assessment (McCartney and Houghton-Carr, 2009), is that all the benefits provided by wetlands must be incorporated in resource planning and decision-making.

1.4.2 The value of farmers' knowledge

Different cultures and groups of people may not only be characterised by different knowledge and perceptions of the world, but they may also have different ideas as to how new knowledge can be produced and validated; that is, they may have different 'theories of knowing' (Lewis, 2004). Whether local knowledge systems should be differentiated from scientific knowledge has been a source of heated debate since Agrawal (1995) argued that attempts to distinguish between indigenous and scientific knowledge are problematic and misguides. Instead of being completely separate, many local knowledge systems may have come into contact with scientific knowledge systems through the long history of exchange and communication between scientific and indigenous culture systems (Gray and Morat, 2003). Furthermore, by setting up a dichotomy between local and scientific knowledge systems, local knowledge systems, which can be highly dynamic, may be forced into static classification systems. However, according to Brokensha et al. (1980) it is important for practical reasons, amongst others related to the source, the accessibility and applicability, to distinguish local knowledge from formal, scientific knowledge.

Figure 1.4. Farmer meetings in Rwanda.

In the epistemic culture of many natural scientists, for example, an important role is assigned to controlled experiments, a separation between independent and dependent variables (Lewis, 2004). Further, natural scientists have a tendency to 'reduce' complex wholes to their basic constituent's parts. This is done from the idea that one can understand the functioning of the complex whole by focussing on the individual parts and the relationship between the isolated variables. Procedures used by farmers to obtain valid knowledge tend to differ from those used by natural scientist. Although many farmers conduct 'experiments' (Stolzenbach, 1994), these tend to have rather different characteristics from scientific experiments. Moreover, in farmers 'epistemology', things like practical experience, farm comparisons, intuition and discussion with colleagues tend to play an important role.

In principle scientists' and farmers' knowledge have the potential to enrich each other and deliver important ingredients for innovation in agriculture (Lewis, 2004). However, this process of enriching is frequently disturbed by the fact that many scientist tend to look at their scientific knowledge as universal, generally applicable and superior to farmers' knowledge (Lewis, 2004). This issue has generated a lot of debate on the usefulness, quality and validity of scientific versus local or indigenous knowledge in farming (Lewis, 2004). In this debate some authors have gone to other extremes, and argued that positivist and reductionistic science inherently produces less relevant knowledge, and that local knowledge is generally superior to scientific knowledge. On the one hand, natural scientists should realise that all knowledge is contextual, and in that sense they cannot claim universality and general applicability. On the other hand, it does make sense to argue that conventional natural science research has something to offer to farmers in specific contexts. Much of the existing local farmers' knowledge needs to be renewed, adapted and supplemented because of rapid changes in the environmental conditions.

In the past, agricultural and natural resource management development projects in Rwanda were often based on top-down transfer of expert knowledge from development agencies to the 'intended beneficiaries'. Farmers' reluctance to adopt or adapt new technologies was blamed on their ignorance, which could be overcome with a higher input of extension activities (Oudwater and Martin, 2003). It is becoming increasingly recognized that natural resource management is a complex process requiring full participation from different stakeholders. This is necessary, given that constraints to natural resource management require a broader management approach that considers not only biophysical aspects, but also farmers' knowledge, socio-economic aspects, and policy considerations. In this respect, only with farmers' participation, a successful practical approach to sustainable wetland management can be developed (Dixon, 2005). Furthermore, for development planning and interventions to be successful it is necessary to fit external technologies and strategies to the local environmental and cultural context (Niemeijer and Mazzucato, 2003). This requires scientists and development workers to develop a thorough understanding of local knowledge and land use practices in relation to the external technologies and development strategies they are promoting.

1.4.3 Intensification of agricultural use of wetlands

Figure 1.5. Field scale experiments on soil fertility management in Rwanda.

In most regions, fertilizer recommendations remain focused on the maximum yields attainable for broad agro-ecological regions (Sanginga and Woomer, 2009), whereas localities, farms and farmers' production objective are highly heterogeneous. Although most of the current research in SSA remains at plot level, the diversity of forces impinging upon it naturally draws attention towards a hierarchical or nested system-based approach that is extended to higher scales, particularly the whole farm and watershed. The rationale for working at the farm scale is the need to improve nutrient use efficiency through better allocation of limited organic and inorganic resources among different enterprises, taking into consideration inherent soil variability within the farming system (Okalebo et al., 2003; Vanlauwe et al., 2006). Variations in supplies of both organic and inorganic nutrients have created strong fertility gradients even within the smallest farms. Smallholder farmers typically remove harvest products and crops residues from their food producing outfields and devote their scarce soil input to their smaller market infields, resulting in large differences in soil productivity overtime between these two field types. Understanding how to manage the limited nutrient suppliers across such fertility gradients is a key component in raising productivity in fields of staple crops.

Different fertilizer responses have been observed in various parts of the same field due to soil fertility gradients. Fofana et al. (2004), in a study in West Africa, observed that grain yields averaged 0.8 t ha^{-1} on outfield and 1.36 t ha^{-1} on infields. Recovery of fertilizer N varied considerably and ranged from 17 to 23% on outfields and 34 to 37% on infields. These results indicate higher inherent soil fertility and nutrient use efficiency in the infields compared to the outfields and underlines the importance of organic carbon and micronutrients in improving fertilizer use efficiency (Fofana et al., 2004).

Historically, fertilizer recommendations have been in excess of crop needs and smallholder affordability but a pro-smallholder approach is to develop recommendations in participation with farmers to generate the greatest return per invested input of fertilizer and labour (Mugabe, 1994; Morris et al., 2007; Chianu et al., 2010). The adoption equation for poor farmers can be changed by increasing the agronomic efficiency of fertilizer through appropriate formulation, timing of application, and practices for increasing soil organic matter. Reducing risks and uncertainty in input markets, local access to affordable packages sizes at the right times, fertilizer promotion in areas with functioning output markets, and demonstrations of soil management use all serve to soil fertility improvement (Yanggen et al., 1998). Increasing agronomic efficiency and changing the ratio of prices of inputs to outputs serve to change the value to cost ratios for fertilizer and its use. Soil fertility recommendations for smallholders must also take into account all nutrient flows and farm practices, particularly the important role of livestock manure as a nutrient source.

Organic matter management and fertilizer, but neither one alone, has the potential to solve farmers' soil fertility problems (Vanlauwe et al., 2001). Soil management practices to maintain soil quantity, structure, nutrients, and proper chemistry can be a partial alternative to the use of the mineral fertilizers but alone cannot meet nutrient demands. Fertilizer alone cannot create big yield increases in degraded soils and low fertilizer use efficiency has proved to be too expensive for poor farmers and is environmentally unsustainable as well. There is a consensus in the scientific community that the highest and most sustainable gains in crop productivity per unit nutrient are achieved from mixtures of fertilizer and organic inputs (FAO, 1990; Pieri, 1989; Giller, 2002; Vanlauwe et al., 2001). There is substantial evidence that when organic and mineral sources are used together they are complementary – organic amendments increase the agronomic efficiency of fertilizer and fertilizer helps increase the returns on organic amendments through positive interactions on soil biological, chemical and physical properties. Past development and policy approaches have been either focused on fertilizer or 'low-input' methods but rarely on both and ignored the essential scientific fact that fertilizers are most effective and efficient in the presence of soil organic matter and well-conserved soil structure. This false dichotomy is resolved by the Integrated Soil Fertility Management (ISFM) framework. Integrated Soil Fertility Management necessarily includes locally appropriate fertilizers and organic resources, the knowledge needed to conduct local experimentation and testing, and locally adapted grain and legume varieties.

In Rwanda much attention is paid nowadays to the use of organic and inorganic fertilizers for nitrogen fixing beans in rotation with maize. The hypothesis is that use of improved technologies will assist smallholder farmers to improve productivity, profitability, and competitiveness of community-based agro-enterprises. On-farm adaptive research through farmer's experimentation is a means to gain high acceptance of the newly developed management approaches.

1.4.4 The need for sustainable wetland management in Rwanda

Many wetlands are fragile and transient ecosystems, easily prone to degradation from natural processes and exploitative human interventions. Depending on the hydrological characteristics of the wetland, their use for agriculture is often a major economic activity undertaken by rural communities to produce crops such as maize, rice and various vegetables (Adams, 1993). Traditionally wetlands have been used as a source of forage resources, with reeds, especially papyrus, being an important source of construction material for fishing boats, houses and local crafts (Muthiri, 1993). In parts of Ethiopia, Uganda and Rwanda, small areas on the margins of wetlands have also traditionally been used for agriculture (Kanyarukiga and Ngarambe, 1998). However, as the demand for productive agricultural areas increases, these traditional wetland use strategies are being superseded by more intensive forms of use, which can involve drainage of entire wetlands and multi-cropping in some of these areas (Roggeri, 1998). Degradation of wetlands poses a risk to the provision of important ecosystem services. But, given that land degradation and climate change profoundly affect SSA and taking account the projection that East and Southern Africa will be critically short of water in the coming decade, extending land improvement to different spatial and temporal scales is extremely important and a challenging area for research and development.

Figure 1.6. Reclaimed wetland in Muhanga (Rugeramigozi), Southern Province, Rwanda.

The suitability of a wetland for specific agricultural activities depends on a complex combination of ecosystem characteristics and the broader socio-economic setting in which the wetland is situated. Consequently, both biophysical and socioeconomic criteria need to be evaluated when considering the suitability of a wetland for proposed agricultural activities. The biophysical suitability, in this context, is a reflection of the "fitness" of the wetland for the specific agricultural use. The requirements for different agricultural activities vary considerably, so biophysical suitability has to be assessed in relation to specific cropping systems. For example, the biophysical characteristics that would make a wetland suitable for cattle grazing are very different from those that are required for rice production, which in turn differ from the characteristics required for maize production. This means that the activities associated with potential agricultural uses need to be clear, so that the suitability of a wetland for such an activity can be accurately assessed.

In many parts of the developing world, the importance of wetlands for the hydrological system and for local communities that obtain their subsistence from wetlands has been ignored by policy makers (Silvius et al., 2000). As a result, the existence of natural wetlands has been threatened by unsustainable development initiatives. Within wetlands these initiatives include the intensification of agriculture, or the complete conversion of wetlands, via drainage, to commercial cropping, dairying or industrial development (Hollis, 1990; Dugan, 1990). Upstream dams and abstraction also pose serious threats to the hydrological system of wetlands (Mwalyosi, 1993). The subsequent impact of such initiatives can be far-reaching and is often irreversible, affecting not only the local communities that rely on wetlands for a wide range of benefits, but also people in downstream areas whose livelihood strategies and subsistence depend upon a reliable supply of freshwater throughout the year. Often, inconsistencies and contradictions between policies at different levels fail to integrate the various objectives of multiple users. The situation is particularly critical in Rwanda, where environmental policies are relatively new and suffer from limited allocation of funds to research (Ngarambe and Kanyarukiga, 1998). One of the main contributing factors to the policy failures is the lack and recognition of farmers' knowledge (Dixon, 2005). A second factor is the lack of knowledge and information about the essential functions and processes of wetlands and the benefits and costs to different users (Turner et al., 2000). Well informed policy making for sustainable reclamation and management of these wetlands is urgently needed to avoid costly degradation of wetlands in Rwanda.

Reclamation of wetlands is by no means an easy operation and requires significant investment in terms of community coordination and land preparation (Dixon and Wood, 2003). In dynamic agricultural wetland situations, a critical aspect to wetland management is the way wetland drainage and changes in land use are affected by government policies and managed by communities. An understanding of the ecological and hydrological dynamics of wetlands and the implications of wetland changes both on the environment and on the livelihood of stakeholders should be used as guidelines to provide accurate responses to this challenge. Therefore, as previously mentioned, this research will test the hypothesis that 'an integrated watershed management approach which includes farmers' knowledge about wetland uses, problems and opportunities is key to development of strategies for sustainable wetland management in Rwanda.

1.5 Overview of methodology

In this thesis a novel for Rwanda, multidisciplinary combination of research methodologies at different scales was used to obtain data for answering the research questions and to test the hypothesis. Working at the national scale, secondary data, policy papers and maps were used. At the watershed scale use was made of a household survey, focus group discussions and the MonQI–tool. And at the smallest scale multi-locational field tests were executed at plot scale.

Household survey

The household survey is widely applied tool in social research, often used to capture general information on the stakeholder groups, and farmer knowledge on specified topics (e.g. Mazzucato and Niemeijer, 2000, Visser et al., 2003). In this thesis results from the household survey were applied in Chapters 2 and 3. For the interviews a predesigned survey form was used with a mixture of closed and open ended questions. This semi-structured questionnaire organised the interview around the main topics but room for new questions is available within a topic depending on the responses of the interviewee. The questionnaires evolved into a flexible tool, covering the central topics but providing ample opportunities for farmers to express new ideas. For Chapter 4, in order to limit the number of potential responses a more formal survey method was chosen. Farmers were randomly selected for the interview (using simple random sampling with replacement) from lists provided by community leaders in the watersheds.

Focus group discussion

A focus group is a form of qualitative research in which a group of people are asked about their perceptions, opinions, beliefs and attitudes towards a product, service, concept, or idea. Questions are asked in an interactive group setting where participants are free to talk with other group members. In the social sciences and urban planning, focus groups allow interviewers to study people in a more natural setting than in a one-to-one (household) interview. Focus groups have a high apparent validity - since the idea is easy to understand and the results are believable. Also, they are low in cost, one can get results relatively quickly, and they can increase the sample size by talking with several people at once (Marshall and Rossman, 1999). In this thesis focus group discussions were used to collect data for Chapters 3, 4, and 5. Key informants and farmers were selected to identify peoples' knowledge and views on wetland use and on agricultural wetland management. Pair wise ranking (Mowo et al., 2007) was used to analyse the results of the focus group discussions and the statistical significance was analysed with the Chi-Squared test.

MonQi

MonQI is a multi-scale and multi-disciplinary approach that monitors management and performance of small scale agricultural enterprises with the aim to improve the quality of farm management, crop production, livelihoods and environment (van den Bosch et al., 1998). MonQI is built upon the hypothesis that integrated monitoring of agricultural enterprises helps to understand these enterprises and paves the way for improvements in social, economic, agricultural and environmental conditions. MonQI provides a description of the existing management situation and provides a research framework for systematic (financial) analysis of agricultural systems at farm level. The MonQI Toolbox is a set of materials (questionnaire, software and manuals) for the application of the methodology (www.monqi.org). MonQI's monitoring and analysis focuses on the household/farm/enterprise and the sub-activities that these include. Its results can be aggregated from the lowest level to the higher levels such as household, village and watershed. The working approach can be summarized in a five step procedure.

1. Monitoring of farm management using MonQI questionnaires.
2. Gathering and checking background data with the Background Data Module.
3. Data-entry using the Data-Entry Module.
4. Data processing using the Data Processing Module.
5. Analysis and reporting of the results.

In Chapter 4 of this thesis the MonQI–tool was used to obtain detailed information on financial indicators at activity level, household level, niche (wetland versus hillside) level and household level. In Chapter 5 the MONQI reporting tool was used to create partial nutrient budgets for each farm household. The budgets were estimated by outflows in crop products (OUT1) and outflows in crop residues (OUT2); and inflows in inorganic (IN1) and organic fertilizers (IN2). Labour flow data between the farm plots within the system provided a comparative basis for analysing subsystems of the farm. The statistical significance of the differences between sites, niches, and farmer resource groups and their interaction was assessed by analysis of variance (ANOVA) of a mixed model, and their means were compared based on LSD at the 5 % critical level.

Field research at different plots of the farm

Often soil fertility management research is conducted only at the plot or field scale, and interactions among various agricultural enterprises and other land uses are seldom considered (Sanginga and Woomer, 2009). The rationale for working at the farm scale instead of at plot scale is the need to improve nutrient use efficiency through better allocation of limited organic and inorganic resources among different enterprises, taking into consideration inherent soil variability within the farming system (Okalebo et al., 2003; Vanlauwe et al., 2006).

Given that the fields of Rwandan farms are distributed over the watershed, for this research it seemed logical to conduct a multi locational trial on three landscape positions; the wetlands (valley bottoms), the foot slopes and the hillsides. In the trial plots were used with 4 -17 replications per landscape position. The trial was set up to test the hypothesis that ISFM practices, involving the integration of appropriate dual purpose grain legumes, with limited amounts of organic inputs and fertilizer, may result in synergistic effects in enhancing maize productivity in Rwandan landscapes. Each trial contained 2 factors (cropping system and fertilizer application), and was laid out as a randomized complete block design.

1.6 Thesis outline

This thesis comprises seven chapters. Chapters 2 through 6 have been developed as separate papers, but in line with the objectives of the thesis research; hence the chapters are interrelated. This general introduction is followed by Chapter 2, which at a national scale classifies Rwandan wetlands and further analyses their functions, problems and opportunities. Chapter 2 also analyses information from a case study conducted in the Rugezi wetland to exemplify the issues that are related to mismanagement of wetlands in Rwanda.

Chapters 3 and 4 deal with research questions 1 and 2. Chapter 3 focuses on farmers' knowledge and perception regarding agricultural wetland management in Rwanda. It presents information and views about the use of wetlands. Focusing on agriculture, it analyses the use of wetlands before reclamation, current use and preferred crops including reasons for the preferences. Chapter 4 explains the contribution of agriculture in wetlands to the farmer's livelihood in Rwanda. In this paper qualitative and quantitative information on wetland agriculture from previous chapters are combined to guide decision making about wetland rehabilitation and evaluate whether new wetlands reclamation is justified.

Chapters 5 and 6 deal with soil fertility. In Chapter 5, the resource use strategies in selected wetlands in Rwanda are presented. This chapter characterizes resource flow strategies within the household farming systems of Rwanda by analysing nutrient flows between wetland and hill slope fields using a farming systems approach in two representative wetlands in Rwanda. A field experiment showing effects of organic and inorganic fertilizer on nitrogen fixation and yield of selected promiscuous soybean or common bean in rotation with maize in different agricultural eco-niches in Cyabayaga and Rugeramigozi catchments is presented in Chapter 6.

Chapter 7 is a synthesis and discusses the hypothesis. It outlines the most important research findings, opportunities for improved (agricultural) wetland management in Rwanda, and research and policy suggestions to support decision making for sustainable reclamation and management of wetlands in Rwanda.

Chapter 2

Wetlands in Rwanda: typology, functions, problems and opportunities

This paper is under review as:

Nabahungu, N.L., Stroosnijder, L., Visser, S.M., Ouedraogo, P., 2011. Wetlands in Rwanda: typology, functions, problems and opportunities. Submitted to: Wetlands.

Wetlands in Rwanda: typology, functions, problems and opportunities

Abstract

This paper provides an overview of the various types of Rwandan wetlands with their functions, problems and opportunities. Besides the analysis of secondary data a field study was conducted in Rugezi wetland in order to exemplify some of the issues about the management of wetlands. A household (n=100) survey and participatory rural appraisal were used to obtain information on the problems caused by wetland degradation. The aim of this study is to support decision making for sustainable reclamation and management of wetlands. Rwanda has 860 wetlands covering 278536 ha. Out of the total surface of wetlands, 148344 ha are cultivated. Wetlands play an important role in supporting the hydrological and chemical cycles and support farmers' livelihood through agriculture for both food and income. Rugezi wetland shows a case where degradation has resulted in falling water levels, which in turn developed into an energy crisis with large social impacts. Wetlands should be recognized as a critical component of long term livelihood and natural resource management strategies, rather than as resources to be used as quick fix solutions. Effective decision-making must balance wetlands conservation and the contribution of natural wetlands to farmers' livelihood. Using an integrated watershed approach might be the best strategic way to contribute to sustainable management and rehabilitation of wetlands in Rwanda. Because this approach has the potential to restore protection benefits, to limit negative effects of transboundary water resources and to conserve biodiversity in both natural and modified wetlands.

2.1 Introduction

Rwanda has a total land surface of 26388 km^2 and a population of about 9 million (NISR, 2008). The population density is with 380 persons km^{-2} one of the highest in Sub Saharan Africa. About 91% of the population lives and works in the rural sector with about 90% depending on agriculture for their livelihood. The agricultural sector is the backbone of the economy and contributes about 41% to the GDP and more than 72% to all exports (REMA, 2009). In Rwanda, intensive farming on hill-slopes has degraded the agricultural land (Clay et al., 1998; Denny and Turyatunga, 1992). Research reports soil losses of 20 to 150 t ha y^{-1} (Roose and Ndayizigiye, 1997) on 15 to 50% of the cultivated slopes and these losses are accompanied with declining soil fertility (Clay et al., 1998). The annual population growth of 2.8% is an underlying driver causing a continuous increasing pressure on natural resources in Rwanda. Since the increased demand for agricultural products cannot be met solely by intensifying agriculture on these slopes, farmers are compelled to extend agriculture into more fragile environments such as steeper hill slopes and wetlands.

Wetland characteristics, reflected in structures and processes, define the ecosystem functions of the wetland (Acharya, 2000). These ecosystem functions comprise the support of goods (e.g. agricultural and livestock products, fisheries, timber and non-timber products, water) and services (e.g. flood control, groundwater recharge and discharge, nutrient cycling, biodiversity maintenance) that benefit various users (Turner et al., 2000). Wetlands are in effect, multi-functional natural reservoirs, and whole communities are dependent upon their productivity and hydrological benefits. The wetland benefits are especially important in the dry parts of developing countries where the strategic importance of wetlands for rural livelihoods is enormous (Scoones, 1991; Silvius et al., 2000). To a lesser but growing extent, this is also true in the wetter highland areas, like in Rwanda, where land shortage is a continuously growing problem due to increased population pressure (Wood and Dixon 2002; Nabahungu and Visser, 2011a).

Wetland agriculture is often a major economic pursuit among rural communities since they provide suitable cultivation conditions for a range of crops such as rice, maize and various vegetables (Adams, 1993). In many parts of Eastern and Central Africa where annual rainfall is high, drainage regimes, which balance water losses with water retention, are an integral part of the agricultural exploitation of wetlands. In some cases up to three crops per year are grown under wetlands conditions. Wetland reclamation and consequent cultivation is often initiated in response to local food shortages, but has major implications for freshwater management (Dixon and Wood, 2003). It has serious impacts upon the regulatory capacity of the wetlands, causing a reduction in water storage and creates a more variable stream flow (Schuyt, 2005). These changes in regulation capacity can have serious implications for local communities and downstream farmers who are dependent upon the stream flow out of the wetlands.

The Rwandan government currently considers wetlands as an important niche for increasing food security and income through the production of rice and other commodities. In Rwanda the total area of wetland is 278536 ha (REMA, 2009). However, out of 148344 ha under cultivation in 2010, only 5000 ha are officially reclaimed, often with a poor design and maintenance (Nabahungu and Visser, 2011b). The rest is unofficially reclaimed and a traditional farming system is practiced by farmers with the goal to provide family food security (Nabahungu and Visser, 2011a).

Astute development and management of wetlands can add considerable value to the benefits that wetlands provide. Nevertheless, care is needed because inappropriate reclamation undermines long-term benefits. Inappropriate design of drainage and irrigation systems often equates to a loss in natural capital, deleterious environmental impacts and harmful consequences to people's livelihoods (Whitlow, 1983; MA, 2005). Furthermore, in general, the larger the reclaimed surface a wetland, the less natural it will become and the smaller the range of ecosystem services it may provide (McCartney and Houghton-Carr, 2009). Hence, a compromise must be reached between direct market-based economic gains and risks to non-market social and environmental derived benefits from ecosystems functions.

Costs of wetland reclamation should consider the multiple functions and services provided by wetlands ecosystems which have direct or indirect influence to human welfare. The ''wise-use'' concept, advanced through the convention of wetlands (Ramsar, 1971), acknowledges that human development necessitates adjustment of wetland ecosystems, but defers from conventional natural resources management because much higher priority should be given to those processes that sustain the ecosystem and the people that depend on them (Ramsar Convention Secretariat, 2007). A key tenet of the ''wise use'' idea, also re-affirmed in the Millennium Ecosystem Assessment (McCartney and Houghton-Carr, 2009), is that all the benefits provided by wetlands must be incorporated in resource planning and decision-making.

Whilst altering wetlands through cultivation can adversely affect wetlands and downstream areas, it is very likely that further development of wetlands for agriculture will be difficult to prevent when alternative livelihood opportunities are lacking in Africa in general (Rebelo et al., 2009) and more specifically in Rwanda (Nabahungu and Visser, 2011b). The conversion of wetlands towards agricultural production areas has increased rapidly over the last three decades due to the acute scarcity of agricultural land. In this situation it is of the utmost importance that wetland reclamation occurs in a sustainable way, to ensure that agriculture does not compromise capacity of the wetland to provide the array of ecosystem services that also support the livelihood of local people (Masiyandima et al., 2004, McCartney and van Koppen, 2004). A good overview of functions, problems and opportunities of wetlands is required to be able to make sound decisions on further reclamation of wetlands in Rwanda.

This paper provides a thorough analysis of the various types of wetlands, their functions, problems and opportunities of Rwandan wetlands to support decision making for sustainable reclamation and management of wetlands in Rwanda. Furthermore, the Rugezi wetland is presented as a case to exemplify issues that are related to problems due to mismanagement of wetlands in Rwanda.

It is noted that literature and documentation on Rwanda dealing with the subject use the words "swamps", "marshlands" and "wetlands". For consistency in this article, except where an author is referred to, the terminology of "wetlands" will be maintained and can be interpreted to mean "swamp" or "marshland" depending on the context.

Box 2.1 The Rugezi wetland

Rugezi wetland in the most densely populated Northern Province of Rwanda is made up of two valleys; the Rugezi valley with a length of 26 km and a width of 3 km and the Kamiranzovu valley with a length of 9 km and width of 2.5 km. The streams of the valleys meet at an altitude of 2050 m and run into lake Bulera, about 200 m downstream.

Population pressure and degradation of uplands are major reasons for people to start cultivating in the Rugezi. Apart from an agricultural function, Rugezi meets two vulnerability criteria, a Biodiversity criterion and a Hydrological criterion. Two hydropower stations, Ntaruka, located between lake Bulera and lake Ruhondo, and Mukungwa downstream from lake Ruhondo are the main sources of hydropower generated electricity in Rwanda. These stations are dependent on the stream discharge from the Rugezi wetland.

Furthermore, Rugezi is home to more than 50 bird species, and more specifically home to 60% of the total world population of the endemic specie Grauer's Swap-Warbler (MINALOC, 2004). Rugezi is of international importance because it is an important water source for both Lake Victoria and the White Nile (Helpage Rwanda, 2004).

According to Hategekimana and Twarabamenye (2008), Rugezi is severely degraded because it has lost large proportions of its hydrological, ecological and energy supply functions. Furthermore, profits from wetland cultivation are reduced as well as income from wild goods. The most factual impacts are: the alteration of hydrological balance, the drying up and the subsidence of peat, the loss of its water purification function, the large fluctuation of the water level and river bed erosion. In 2005 the government of Rwanda adopted measures to prevent all human activities in the wetlands. Rugezi wetland was registered as Ramsar site in 2006 (REMA, 2009) and is now fully protected.

2.2 Methods

Existing studies and reports from Ministries and government agencies are used to analyse the typology, functions, problems and opportunities of wetlands in Rwanda. The vulnerability criteria developed by MINITERRE (REMA, 2009) are used as a base and are further developed to provide guidelines for wetland use and management based on wetland ecosystem and services provision. GIS based maps provide an overview of the distribution of wetlands and wetland types in Rwanda. In addition, the maps were used to extract information on the extent of agriculture in wetlands and of proposed Ramsar sites.

The Rugezi wetland case provided a detailed biophysical and economic analysis of the problems caused by wetland degradation. Participatory Rural Appraisal (PRA) with selected farmers (elders and leaders) was combined with a detailed household questionnaire (100 households). Key informants were consulted and interviews were conducted with officers from government agencies (REMA and ELECTROGAZ) and from districts in charge with agriculture. Information from key informants was on wetland degradation, the related power shortage and its consequences, the potential of using Rugezi wetland as tourism site, and on historical land and crop management practices in Rugezi wetland. The type and history of wetland use, wetland hydrological behaviour, and the importance of the wetland to the local communities in relation to the surrounding upland environment were assessed through focus group discussion with village elders.

2.3 Typology and distribution of wetlands in Rwanda

Finlayson et al. (1999) describe the confusion caused by different definitions of wetlands. In general the word ''wetland'' encompasses wetlands and marshes, generally located away from the coastal zone. However, Rebelo et al. (2009) also includes coastal wetlands, such as tidal lagoons and mangroves in the definition. The Ramsar convention on wetlands has agreed an even wider definition of wetlands that includes lakes and rivers as well as artificial wetlands such as reservoirs and rice fields (Mistch et al., 2000). The definition used by the convention is gaining wider acceptance. However, in literature it is not always clear which definition was used and this causes confusion and uncertainty when inventory data from different sources are compared.

In ''The Law Determining the Use and Management of Marshlands in Rwanda'' "Marsh" means a plain area between hills or mountains with water, high biodiversity, and vegetation associated with marsh environments. For the English language version of this law, the term "marsh" is considered to be synonymous with the term "wetland" which is used in the English language version of "The Land Law" and in "The Environment Law". Thus, in Rwanda "wetland" means all lowland and comprises the complete valley bottom, both the well-drained and the wet part.

An inventory of wetlands conducted in 2008 by REMA showed that Rwanda has 860 wetlands covering a total of 278536 ha, which is 10.6% of the total surface of Rwanda. Wetlands can be grouped in three main categories (Figure 2.1); natural vegetation (41% of the inventoried wetlands), cultivated (53%; 148344 ha) and fallow lands, which were previously under cultivation (6%). Rwandan wetlands generally have rather small flood zones. Water tables are near or just above the lowest ground surface during the rainy season and may drop till several cm below the lowest ground surface in the dry season (Chemonics International Inc., 2003). For sustainable wetland use and management it is important to know the physical and ecological characteristics of wetland. REMA (2008) distinguished seven wetland types based on such factors as relief, altitude, soil type, vegetation, hydrology, surface area, catchment's slope and population density (Table 2.1).

2.4 Functions of wetlands in Rwanda

Given the importance of wetland ecosystems, a vulnerability criterion in terms of ecosystem and service provision can assist with land use planning and wetland management. The vulnerability criteria developed by MINITERRE (REMA,2009) are used as a base and are further developed. The criteria are related to: Biodiversity (B), presence of Peat (P), Hydrology (H), Natural Reserve (NR), and presence of (Country) borders (Cr). Here the criteria are further elaborated and Table 2.2 gives an overview of the potential use conditions that wetlands with a specific criterion have.

Wetlands that carry the Biodiversity (B) criterion have ecosystems containing specific flora and fauna. The destruction of such ecosystems results in the reduction or loss of biodiversity. Some elements of the fauna of the wetlands are recognized by law as endemic and classified by the Convention on International Trade in Endangered Species (CITES) in order to ensure their protection. Wetlands with a biodiversity criterion are periodically home to migratory birds and are considered as ecosystems of international importance under the Ramsar Convention (REMA, 2009).

The presence of Peat (P) makes wetlands vulnerable because they consist of layers of organic material which are constantly waterlogged and therefore unstable. The development of wetlands with peat usually causes risk of self-combustion (fire) and subsidence. High altitude peat wetlands are generally water reservoirs for areas located downstream. Consequently, the draining of peat lands may cause significant negative impacts downstream, risk of subsidence and drying out of the wetlands.

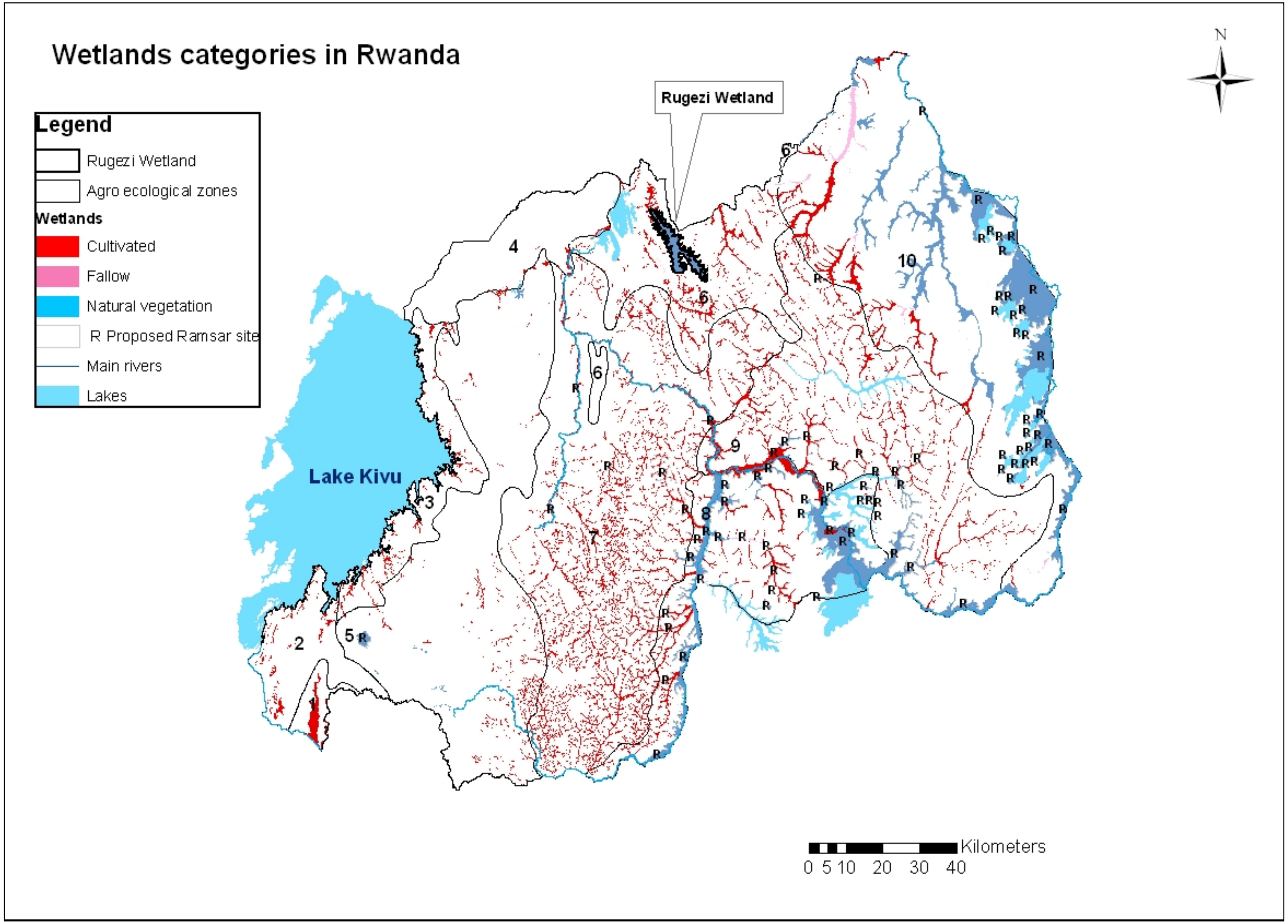


Figure 2.1.Spatial distribution of wetland categories and proposed Ramsar sites in Rwanda, Numbers 1- 10 represent Agroclimatic zone explained in Table 2.1(adapted from REMA, 2009 and GEF/WB, 2005)

Table 2.1. Wetland types in Rwanda*: altitude, soil type, functions and corresponding agro-climatic zones, which are indicated with the number in figure 2.1.

Type	Altitude	Soil type	Vegetation	Function	Agroclimatic zone
High altitude wetlands	>1800	Histosols	Miscanthus, Violaceus, Cyperus, Latifolus, Lobelia, Ericaceae, Sphagnum Reclaimed-under crop	Water reserve, Water Source, Biodiversity reserve	Crete Z/N (5) Buberuka HL**(6) Volcanic land (4)
Mid altitude Impara wetlands	1550-1800	Histosols	Cyperus Papyrus, Syzygium	Water reserve, Water source, filter	Impala (2)
Mid altitude wetlands along lake Kivu	1400-1500	Inceptisol, Nitosols	Cyperus, Papyrus Cyperus, Latifolius Typha	Biodiversity	Kivu Lake Border (3)
Mid altitude central plateau wetlands	1400-1800	Inceptisols	Cyperus latifolius,	Water reserve, Agriculture	Central Plateau (7)
Low altitude wetlands of Kanyaru, Nyabarongo and Akagera	1200-1500-	Histosols	Cyperus, papyrus Phoenix, Reclinata, Syzygium, cordatum	Water Reserve, Water source, Dam, Biodiversity	Mayaga, Bugesera(8)
Low altitude wetlands in the East	1200-1500	Vertisol	Typha Domingensis Polygonum pulchrum	Water reserve	Eastern Plateau (9) Eastern savannah (10)
Low altitude Wetlands of Imbo	<1000	Vertisol	Typha, Pragmites, maurritianum	Agriculture	Imbo(1)

Adapted from REMA, 2008 and 2009

The hydrology (H) criterion is important because it concerns the water conditions, which determine the health of the wetland ecosystem. Wetlands with a hydrology criterion, especially those at high altitudes, are sources of major rivers. Drainage causing the loss of the regulation function of these wetlands may lead to drought in downstream areas, increased runoff and erosion or disruption of the local climate. A special class under the wetlands with a hydrology criterion are the wetlands with a dam criterion (Hd) and wetlands with a water supply for towns criterion (Hw). Wetlands with a dam criterion are the wetlands located between a lake upstream and a river downstream and serve as a buffer for water. Their exploitation may lead to the drainage and ultimate disappearance of the upstream water reservoir. Drainage of wetlands with a town water supply criterion can cause disruption in water supply, with important socio-economic impacts like water-related diseases or the interruption of industrial production in case it relies on the use of the water as part of their processes.

The presence of a park or a natural reserve (NR) is an important vulnerability criterion for wetlands that are home to wild animals. These wetlands not only provide the water resources for the animals in the park, they often function as buffer zones between the park and the neighbouring populations.

Cross border wetlands (Cr) are those which straddle several sectors, district or countries. Most efforts to understand and safeguard natural resources and cross–border ecosystems are often circumscribed within the limits of administrative entities (sectors, districts and countries). However, if there are no joint management efforts, the effects of mismanagement of a part may affect the whole wetland ecosystem. Joint management is more difficult in the case of wetlands belonging to several countries. For this reason, these wetlands should have a special status.

In Rwanda, the wetland debate has seen two dominant views, one promoting the full protection of wetlands as fragile ecosystems the other encouraging rapid and complete transformation of wetlands for agricultural use. It seems clear that a more nuanced approach to wetlands is needed which includes the perspective of both local users and the other users that can be affected by the role and functioning of the wetland in the hydrological cycle.

Table 2.2 shows that out of 860 wetlands in Rwanda, 38 wetlands (56120 ha; 20% of the total wetland surface) are proposed for full protection. Table 2.2 further showed that, for 475 wetlands with a total surface of 206732 ha (74%) exploitation is possible under specific conditions. The management of these wetlands should involve both local level capacity and policy development. Finally Table 2.2 proposes 347 wetlands; 15689 ha (6%) for exploitation under a basic Environmental Impact Assessment (EIA). The wetlands proposed for a use without specific conditions do not a priori need specific cautions. However, one should underline that, whatever is the type it belongs to; each wetland has specific characteristics that a general classification never can reflect. It is therefore essential that each reclamation project is carefully studied through pilot projects, including not only an environmental impact assessment but also an assessment of erosion risk at the catchment area level.

Box 2.2 Causes of the Rugezi wetland degradation

The wetland reclamation policy developed in the 1960's provided the required legal framework to solve the land scarcity problem through the distribution of new land in the wetland. Two projects; one executed by the Japanese International Cooperation Agency (JICA) in 1968 and one executed by the International Fund for Agricultural Development (IFAD) in 1996 realized the reclamation of three branches of the wetland. Through the broadening and deepening of the main channel and the construction of lateral channels excess water was drained fast and new agricultural land was gained. However, the projects resulted in the breakdown of the hydrological balance, a drop in the water table of 50 cm and land subsidence of 30 cm (Hategekimana and Twarabamenye, 2008).

In the period between 1978 and 2000 the population increased with approximately 75% (Hategekimana and Twarabamenye, 2008) and the population density grew from 337 to 577 persons km^{-2}. With agriculture as main source of income in the region, this led to the exploitation of the steep hillsides and the reclamation of the low hillsides adjacent to the wetland. Cultivation of the steep slopes resulted in an increase in overland flow and an accelerated soil erosion. The contribution of the hillsides to groundwater recharge was strongly reduced and the erosion led to sedimentation throughout the wetland strongly reducing its filtering capacity (Hategekimana and Twarabamenye, 2008).

ELECTROGAZ started to improve wetland drainage in 2000. These works comprised the straitening of meanders and an increase in width and depth of the main stream bed. This increased the maximum discharge from 1.5 to 4.8 $m^3 s^{-1}$. But the increase in stream velocity and fast delivery of higher storm peaks reduced the retention time of water in the wetland resulting in a progressive drainage of the wetland. A study by Helpage Rwanda in 2004 showed that the average discharge from the Rugezi wetland decreased with 50% compared to the average discharge in 1957-1970. After the drainage in 2000, the rural population hurled itself massively in the wetland to start cultivating the dried parts of the wetland which formed virgin and thus fertile new land (Hategekimana, 2005).

Table 2.2. Potential use of wetlands in relation to their vulnerability.

Proposed use	Vulnerability criterion	Type of wetland	N	Area(ha)	Use conditions
Total protection	B(*); recognised by RAMSAR	High altitude wetland, Mid altitude wetlands along lake Kivu, Low altitude wetlands of Kanyaru and –Nyabarongo and Akagera	5	6736	Prohibited use according to legal dispositions ruling ecosystem listing
	NR (**); at least partially , including their buffer zones (**)	Low altitude wetlands of Akagera, High altitude wetland	22	37242	Prohibited use according to legal dispositions ruling ecosystem listing.
	H (***)		3	8237	Prohibited use
	Hd(***)	Low altitude wetlands of Kanyaru–Nyabarongo	8	31905	Prohibited use
	P; without high altitude peat wetlands	Low altitude wetlands of Kanyaru –Nyabarongo and Akagera	78	111121	Generally spring wetlands, therefore prohibited
Total wetlands requiring total protection			**116**	**195241**	
Use under specific conditions	Cr	Low altitude wetlands of Kanyaru and Akagera	25	85640	Management by joint committees
	Wetlands belonging to 2 or more Districts	Wetlands of Kanyaru and Akagera	182	145768	Management by inter-District joint committees
	High altitude (>1800 m) peat wetlands (****)	High altitude wetland, Mid altitude Impala wetland	9	13104	Specific management authority
	Other peat wetlands				
	Hw	Low altitude wetlands of Kanyaru – Nyabarongo, Mid altitude central Plateau wetlands	20	7733	Careful superficial drainage; prohibited use downstream the wetland. No other use in the wetland in 10 meters all around. Avoid agriculture intensification, can allow a traditional use
	Wetlands providing drinking water to villages and town	All	?	?	Use but keeping the water table level; regulations of fertilizers and pesticides use.
	Wetlands of Bugarama depression H	Low altitude wetlands of Bugarama depression	6	3032	Rational water management, extension of irrigation is subject to a hydrological study -- downstream can be irrigated
	Wetlands with ≥100 ha or more under cropping	Low altitude wetlands of Bugarama depression	365	130873	Specific management authority
	Wetlands of ≥15 ha, partially under cropping, covered by ≥30% of natural vegetation	Mid altitude central Plateau wetlands, Low altitude wetlands in the East	102	127402	Prohibited use of the area with natural vegetation, considered as buffer zone
	Wetlands of <15 ha, partially under cropping, covered by ≥70% of natural vegetation	Mid altitude central Plateau wetlands	1	3	Prohibited use of the area covered by natural vegetation
Total wetlands proposed to be used under specific conditions of EIA			**475**	**206732**	
Total wetlands proposed for use without specific conditions			**347**	**15684**	

(*) Hosting endemic threatened species (IUCN and CITES) (**) Surface of those wetlands included inside the parks only. (***) Total surface of those wetlands (****) At least partially peaty. B:Biodiversity; NR: Natural resources; H: Hydrology; Hd: Wetlands with dam criterion; Hw: wetlands with a water supply for towns; P: Presence of peat; Cr: Presence of borders; EIA: Environmental impact Assessment.

2.5 Problems with wetland use in Rwanda

The large population growth in Rwanda has resulted in an enormous pressure exerted on wetlands resources. Currently sustainable wetland use is threatened by agricultural intensification, exploitation of natural resources, urbanization inadequate wetland policy and lacking technical capacity of stakeholders.

2.5.1 Agricultural intensification

Given the land shortage in Rwanda, wetlands are put under intensive cultivation for crops such as sugarcane, rice, flowers, sweet potatoes, and Eucalyptus (GEF/WB, 2005). The impact of the intensification is evident in many wetlands. Wetlands under traditional use for livestock, fodder, water, craftwork and small-scale agriculture, have the capacity to regulate the water flow. When drained and used for intensive agriculture, the water is conveyed rapidly downstream reducing the wetlands ability to buffer peak flows, retain sediment and hold water. The agricultural intensification has resulted in a year round cultivation in many wetlands. As a consequence water demands are high water, especially when combined with the policy recommended rice production (Nabahungu and Visser, 2011b). Rice production in many wetlands is now hampered by water availability (Nabahungu and Visser, 2011a,b).

2.5.2 Overuse of natural resources

Apart from an agricultural function, wetlands are used for many other functions (Table 2.2). The use of wetland for hydropower generation and as mine for sand, gravel, clay and peat forms the most direct threat for the wetlands. Hydropower plants only function when sufficient water is available and as such have a high water demand. Many of the existing hydroelectric power plants are run-of-the river connected to wetlands schemes, with minimum storage making them very dependent on stream-flow for their operation, a constraint that becomes particularly significant during the dry season. In addition, the hydroelectric power plants are more vulnerable to sedimentation damaging tubing and turbines because of the limited storage capacity of the wetlands (Andrew and Masozera, 2010). Dropping water levels may lead to enormous economic losses. Due to the high economic pressure unsustainable wetland management decisions can be taken, and the consequences may be devastating as is clearly shown in the Rugezi case.

Wetlands are also used as mines for sand, gravel, clay and peat. Clay is used for bricks, tiles and pot construction. Peat is used as fuel in prisons, industries and schools as an alternative energy source for wood. Mine exploitation is rarely organized, disturbs the wetlands ecological balance and often brings about water pollution and diversion of the river through silting, watercourse drying up and results in landscape upheaval in general.

Wildlife in the natural wetlands can be freely hunted as long as the wetland is not related to a park or national reserve. As result of the hunting, animals disappear or migrate towards other habitats clearly reducing the animal biodiversity in the wetlands. Furthermore, the natural vegetation is exploited for construction material, and medicinal plants are collected by traditional healers. The consequent reduction in vegetation cover leads to an increased evaporation from open water.

According to Dixon and Wood (2003), multiple land use can both ensure the maintenance of the wetland hydrological functions and sustain production of a range of benefits such as dry season harvests, construction and thatching material and medicinal plants. The main threat in the multiple use of wetlands lies in the uncontrolled use, which may result is overexploitation.

2.5.3 Urbanization

According to REMA (2009), urbanization and its associated development of houses has a direct impact on the physical characteristics of the soil. Water infiltration will reduce as a result of urbanization and so runoff and soil erosion will increase. For all types of wetlands the competition for water and reduced infiltration lead to the more or less gradual drainage of the wetland, which affects its capacity for sedimentation and flood control.

In Rwanda, the urbanization effect is especially remarkable in Kigali and to a lesser extent in other provincial towns like Rubavu, Musanze, Huye, Muhanga, Ngoma and Kamembe. Construction of houses and pavement of roads has reduced the surface area available for infiltration. The increased runoff causes erosion on bare soils and siltation of water ways in the lower parts of the wetlands. In those areas where open sewers and exposed drainage canals are present, the runoff water carries along the domestic waste, which is deposited in the downstream wetlands. In the Gikondo and Nyabugogo wetlands in Kigali, a large risk of diseases like diarrhoea is present during periods of lower discharge, due to the presence of open sewers upslope.

Also associated with urbanization is watershed destruction and dumping of untreated effluent in rivers and wetlands (MINIFRA, 2003). In urban areas wetlands are most likely to be used as dumping sites for waste or wetlands may be converted to other forms of land use, such as residential and industrial development, road construction, or aquaculture. The Gikondo industrial area located in Gikondo – Nyabugogo wetland greatly affects the ability of the wetland to clean wastewater and control siltation of streams (REMA, 2006).

2.5.4 Inadequate wetland policy

Environmental management as a public policy domain is still at its early stage of development, partly due to the frequent transfers of the Department of Environmental Management from one Ministry to the other during successive Ministerial reorganizations (GEF/WB, 2005). A few recent policy developments characterize Rwanda's environmental regulation framework: (1) the establishment of an implementing agency underneath the environmental ministry in 2005 (Rwanda Environmental Management Authority), (2) decentralization of environmental responsibility, and (3) the establishment of a National Fund for the Environment. These efforts should increase Rwanda's ability to handle environmental challenges. However, continuous modification to the environmental policy structure in the last decade hampers Rwanda's ability to monitor, implement, and manage environmental conditions and projects (Willetts, 2008). In particular, communication between the relevant ministries – environment, infrastructure, economic planning and finance, agriculture, and tourism – is inefficient or non-existent.

Since Rwanda became independent in 1962, wetland management is a responsibility of MINAGRI. In response to demographic growth and the related increased demand for food, the main objective of MINAGRI was wetland reclamation to improve food production (Hategekimana, 2005). In that period from the 60's till the 80's, the hydrological and ecological importance and vulnerability of wetlands in terms of water quality and quantity management, wildlife habitat and recreation were unknown. Currently the lack of a spatial planning policy and a distinction of wetlands types in Rwanda complicate wetland management in terms of their resources allocation. Although some draft texts for laws exist, they do not correctly define measures for wetland conservation. The appropriate reclamation techniques and procedures are not well described. Furthermore, some policy papers are contradicting which leads to wetlands mismanagement.

2.5.5 Low technical capacity of different stakeholders

An assessment conducted by the government of Rwanda during the preparation of baseline of RSSP (Rural Sector Support Program) (RSSP, 2001) showed that the performance of agricultural wetlands is unsatisfactory. The reasons for this poor performance include (i) a poor design of water control works; (ii) unclear property rights and access right to wetlands; (iii) unavailability of adequate skills in rural engineering (REMA, 2008). One important finding of the assessment study was that the conversion of the wetland did not take into account the opportunity costs of developing these critical ecosystems.

In 2009 approximately 53% (148344 ha) of the wetlands area was used for agriculture. Of these 5000 ha were officially reclaimed for production and used all year round (MINERENA, 2008). However, out of this 5000 ha more than 4000 ha have problems with the water distribution, leading to water shortage at one location and logging at another. These agricultural wetlands need rehabilitation.

Even though many Rwandan farmers do have experience with and knowledge on wetland agriculture, their knowledge is based on traditional management. Agriculture in officially reclaimed wetland requires a different management approach. Due to inadequate farmer training by extension personnel, many problems arise in agriculture in reclaimed wetlands ranging from poor irrigation schemes, eutrophication, over drainage, and low productivity. This is mainly related to the fact that the extension personnel is often insufficiently trained in adapted technologies specific to wetlands. The Environmental Directorate in MINITERE lacks sufficient trained staff with adequate technical skills in the required areas of specialization (GEF/WB, 2005). The Department is further constrained by coordination failure among public institutions that are involved in environmental policy implementation. It especially lacks inter-sectorial coordination mechanisms and credible and action-oriented environmental information to assist policy-makers (GEF/WB, 2005).

2.6 Opportunities

2.6.1 Role of wetlands in economic development and contribution to farmer's livelihood in Rwanda

Wetlands in Rwanda have been used in different ways and have a great role to play in the national economy. Most of the ecosystem services related to wetland accrues to local or national beneficiaries. Rwandan cities depend on wetlands for their water supplies and electricity generation. Of the total installed electric power generation capacity of 41.25 MW, hydropower accounts for 65%, while thermal power accounts for 35% (Safari, 2010). Rwanda's agricultural policy prioritizes wetlands for specialized crops and irrigation system development in order to increase production efficiency and to meet economic goals. According to Mellor (2003), about 15% of expected growth in GDP to be derived from agriculture was expected to come from the use of wetlands. Vision 2020 has fixed specific national objectives for the period 2002 to 202. One of the objectives is the development of 40000 ha of wetlands for agricultural use (Willetts, 2008).

Biodiversity supported by the wetland ecology is the most important ecosystem service and forms a large potential for recreation and ecotourism. Rwanda wants to increase its national tourism sector from $26 million U.S. to $100 million U.S. by 2012 – with a large focus on ecotourism in amongst others wetlands. Improving access and marketing of rural wetlands can play an important part in this objective. Especially the high altitude wetlands host a higher number of vegetation species compared to other wetlands (REMA, 2009). This may result from specific ecological conditions but also from the size and current protected status. Furthermore, Rwanda hosts a number of migrating birds species protected by CITES. These migrating species have been observed in Murago, Gishoma, Rweru- Mugesera complex, on the lakeshore of Lake Ihema (REMA, 2009).

Wetlands in Rwanda support the livelihoods of many poor people through agriculture for both food and income (Nabahungu and Visser, 2011b). A study conducted by Nabahungu and Visser (2011b) showed that, in Cyabayaga, the contribution of wetland cultivation was 74% ($ 1901 U.S.) to gross margin (GM) per household per year. Thus wise use of wetlands can contribute highly on economic development and improve farmers' livelihood.

Box 2.3 Economic consequences of the Rugezi wetland degradation

A major economic effect of the degradation of Rugezi, is the energy crisis caused by the dropped water levels of the lakes as a result of declined discharge from Rugezi (REMA, 2009). In 2005 Electrogaz had a power supply shortage of 42% and the resulting power failures forced individuals and production companies to purchase private generators (ELECTROGAZ, 2005). This led to an increase in production cost and a price increase for consumer goods. To be able to meet demands Electrogaz has purchased a number of diesel powered generators, for which daily operation costs were estimated US$ 65000 (EIU, 2006). As a consequence of the power shortage, the electricity bill has hiked from 0.1 US$ to 0.25 US$ per Kwh since 2006.

The loss of water regulating capacity of Rugezi led to the occurrence of floods, which never occurred before 2000. 69% of the farmers have experienced damages from floods and in some incidents people as well as animals were killed by floods. The drop of water level also seriously affected boat transportation. Before the wetland degradation, approximately 20 small ports were present from where people could travel by boat. Approximately 70% of the farmers used to depend on boat transportation to and from markets. Furthermore, this transportation system was used for the import of food and construction material from Uganda. Today boat transportation in Rugezi is only practiced in the southern part of the wetland. This has reduced income of boat owners and increased prices and changed availability of goods that were previously easily transported by boats to markets in the region.

Before degradation harvesting wild goods could provide substantial income. The table below provides an overview before and after degradation. Whereas hunting and fishing used to be dominant activities especially for the poor and landless people before degradation (de Vos, 1986), in 2005, hunting activities were abandoned due to a lack of wild life and fishing activities are reduced to only 2% of its former extend and fish is no longer exported to Tanzania. Before 2005 fishing could provide an annual income of $35 and weaving $30.

Harvested wilds goods (in kg year^{-1}) before and after degradation (Hategekimana, 2005)

Product	Before (1990)	After (2000)
Wild medicines	43	0
Wild fruits	113	16
Wild vegetables	100	350
Thatching grass	3800	180
Woven goods	6098	100
Leaf litter	1500	102
Pottery clays	7200	0
Livestock fodder	3000	770
Wild animals	2400	0
Wild fish	13135	347

The reduced presence of the natural vegetation resulted in a limited availability of fuel and the degradation of thatching grass resulted in the reduced availability of materials to create woven goods. Prices for woven mats, which are used by the local people in the houses, have increased by 300% over a period of 5 years. The degradation of reeds resulted in its limited availability for building material and furniture and reduced availability of litter which was used as fertilizer.

The reduced availability of natural goods directly affected people depending on them, e.g. the women who used thatching grass to weave mats. It also affected the economic value of the products itself and their replacements. As a result welfare of the communities was negatively affected (REMA, 2008). The reduced availability of fodder, affected livestock keeping in the region and contributed to increase poverty.

2.6.2 Knowledge, political and public awareness

In 2002, the MINAGRI developed a master plan for wetland development, soil conservation and watershed protection funded by the African Development Bank (ADB) (MINAGRI, 2002). This scheme led to wetland classification in accordance with their hydrological aspects, their level of degradation and recommended the conservation of highland wetlands as integral part in water resources management. In 2003, the Ministry of Environment, Lands and Mines (MINITERE) with support from Global Environment Facility (GEF), finalized the Action Plan on environment and biodiversity conservation. This study showed that, wetlands play an important role in water management and biodiversity conservation, but they were still threatened by agricultural encroachment, overexploitation of plants and fish. In May 2003, MINITERRE recommended a study on the assessment of biological diversity of wetlands. This study came up with a classification of wetlands of international importance classified as Ramsar sites. It recommended that those sites should be under conservation by implementation of an ecosystem approach.

The described processes show that, knowledge development and a raising political and public awareness in wetland management started rather late. However two years after publishing reports, the Ramsar convention was ratified by the Government. And due to the Ramsar conservation status Rugezi wetland restoration stands as a testimony of rehabilitation efforts towards sustainable management of natural resources for development in Rwanda.

With the increased knowledge on wetland contribution to livelihoods (e.g. Nabahungu and Visser, 2011a), the opportunity costs of wetland development can be taken into account. As a result, better founded decisions can be made on the development of wetlands, given their location and the range of goods and services it provides in the natural state.

2.6.3 Indigenous knowledge in wetland use

Improved wetland management in Rwanda must acquire different types of knowledge from a variety of sources, through a range of different channels, both indigenous and external in origin. In those communities where wetland use has a long history, the intergenerational transfer of ancestral knowledge should play a vital role in providing farmers with basic information on wetland management.

In Rwanda evidence suggests that wetlands have been managed by local communities in a sustainable manner for generations, and that through this management wetland use does not necessarily lead to degradation (Nabahungu and Visser, 2011b). Wetland utilization is often based on community management strategies that have evolved over time through the development of ‘indigenous’ or ‘local’ knowledge, via the passing down of ancestral knowledge and/or the process of innovation dissemination. Furthermore, indigenous knowledge has been recognized in recent decades as making an important contribution to natural resource management and sustainable livelihoods, particularly in the developing world (DeWalt, 1994; Nabahungu and Visser, 2011a). The ‘social resilience’ of a population, which possess both this knowledge and the capacity to adapt and apply it in the face of changing environmental or socio-economic conditions, is regarded as an important prerequisite to sustainable natural resource management (Adger and Luttrell, 2000; Berkes et al., 2000).

Not all natural resource management strategies based upon traditional indigenous knowledge are necessarily sustainable. A shift from sustainable to unsustainable natural resource management can occur when environmental or socio-economic change proceeds at a rate which exceeds the capacity of communities or individuals to develop their indigenous knowledge adapt their management strategies and cope with change (Farrington and Martin, 1988; Grenier, 1998; Adger and Luttrell, 2000). Understanding how this adaptive capacity functions, and how it is influenced, is fundamental to understanding the relationship between indigenous knowledge, social capital and the sustainability of natural resource management. Therefore, local level consultation and recognition of local knowledge combined with scientific knowledge should be a perquisite for wetland policy recommendation if wetland benefits are to be sustained.

Box 2.4 Restoration of the Rugezi wetland

Restoration works in Rugezi started in 2005 with preventing people from working in the wetland area. A process which was further strengthened when the wetland obtained its Ramsar state in 2006. Pottery activities, which traditionally were the main income source for the Batwa people, have been totally prohibited due to the degradation caused by the clay harvesting. This not only affected the Batwa, who were forced to find another source of income, it also affected other social groups in the region since the majority of the population cannot afford to buy iron pans.

Since the restoration of Rugezi wetland, the water level of Lake Bulera has increased with 4 meters. Power production, which had decreased till the end of 2007, started to increase from 2008 onwards and in 2010 the hydropower plants supported by Rugezi are operating nearly at its full capacity, reducing by half the use of diesel generators for electricity production (Mukankomeje, 2010).

In October 2010, Rwanda won the Green Globe Award category in the African region for the restoration of the Rugezi wetland. The Green Globe Award was given to Rwanda in a ceremony in the middle of the Convention on Biological Diversity (CBD) held in Nagoya, Japan.

According to Mukankomeje (http: //twitter.com/atwahirwa 26 October 2010) Rugezi is now characterized by lush green vegetation and rich fauna. The restoration of the Rugezi reopened a corridor for migratory birds and fishes, and provides good conditions for many plant and animal species, particularly the endangered and threatened species (REMA, 2009). Rugezi wetland restoration stands as a testimony of rehabilitation efforts towards sustainable management of natural resources for development in Rwanda.

2.7 Discussion and conclusion

The study of Rugezi wetland has provided findings that are very useful to the understanding of functions, problems and opportunities of wetlands in Rwanda. Degradation affects individuals, households, communities, the economy and beyond. An insufficient supply of electricity in Rwanda adversely affects the economy now and in future and is closely attached to the impacts of degradation of wetlands. The impact of degradation on individual households and communities is alarmingly negative. Children and women have to travel longer distances to collect water. Firewood as an important source of energy to rural livelihoods has become scarce while there is no evidence of growing alternative sources. Economic and social activities such as weaving of mats have been disrupted affecting incomes of households. Pottery an important socio-economic activity of a social group, particularly the Batwa, has disappeared.

The Rugezi case further illustrated a clear example of how degradation of such ecosystems can have multiple consequences. The effects include also those that are economic in relation to the population in general and to local communities in particular. It also sheds light on the implications of destroying wetlands. Most of the time, wetlands are destroyed by human development because, as Bennet and Morrison (1999) assert, there are strong financial incentives for the natural resources that comprise wetlands to be developed.

This paper bears evidence for the urgent need for more concerted efforts in managing fragile but important ecosystems such as wetlands. Finally the case study has further reinforced the argument that there is a circle of inter-dependency between degradation of wetlands, energy crisis and therefore, economic performance of Rwanda. More sustainable use of natural resources would unleash multiplier effects to several other sectors of the economy and GDP as a whole.

Presently about 15% of expected growth in GDP to be derived from agriculture is expected to be from utilisation of wetlands (Mellor, 2003). However if it will be large scale and commercial farming that will gain from the exploitation, it is likely that the majority of the poor will not benefit. Large scale commercial farming will not lead to sustainable growth as the gains will at the same time destroy a multitude of ecosystem services the poor derive from the wetlands. The community as a whole will lose the non-economic services that are nonetheless life supporting.

There is the need to raise awareness on the importance of wetlands and their multiple benefits. Whilst those who derive their livelihoods directly from wetlands are all aware of the value of water supplies, wetland craft materials, and hungry season harvest, beyond this local level wetlands still tend to be regarded as places which should be conserved as their natural condition according to ministry of environment (REMA, 2009), or as areas with little commercial value which are only productive when converted in for intensive agricultural use (MINAGRI, 2002). Awareness raising should, therefore, primarily target policy-makers in the agriculture and water resources sectors, so that the multiple benefits from wetlands and multiple recipients of these benefits are considered in a holistic catchment-wide context.

There is also a need for awareness raising at the local level, where community leaders and the members of wetland management committees must recognize the full range of stakeholders who use these areas and involve them all in wetland decision making processes. This will ensure that wetland use is not just ecologically sustainable but also socially sustainable.

Wetlands should be recognized as a critical component of long term livelihood and natural resource management strategies, rather than as resources to be utilized as quick fix solutions to address food and water shortages, as has been typified by Rugezi wetland. The role of wetlands in recharging groundwater and thereby securing safe water supplies, and in moderating stream flow with its implications for flood control and hydropower production, are two examples of the wider benefits from wetlands that need to be understood among planners and policy-makers. Furthermore, more attention has to be given to the development of sustainable wetland use technologies that meet the needs of communities and the hydrological system. For example cropping regimes that will require less alteration of the wetland environment and less disruption of the hydrological regimes.

There is no reason why standard valuation of wetlands cannot be carried out in Rwanda. This valuation could help environment compensation to farmers who derived their livelihood in the wetlands after evicted from wetland for conservation (e.gRugezi). Coherent methods particularly the Willingness To Pay and Contingent Valuation Methods have been used effectively in various cases in the world (see Barbier et al. 1997). If for example estimates by Barbier et al. (1997) for a wetland in Nigeria is a rough estimate to work with then a hectare of wetland would have Net Present Value (NPV) of US$ 51, which is about a fifth of per capita income of a Rwandan in 2005 (REMA, 2009). This would mean, discounted over 50 years that the wetlands of Rwanda have a value of about 2 million dollars a year as direct value only. However a more safe approach in the context of preserving the ecosystem would be the precautionary policy approach where exploitation is weighed against future damage to the rich ecosystem in the short and long term perspectives.

Using a watershed approach appears to be the best strategy for the management and rehabilitation of wetlands in Rwanda. Such an approach would be designed to:(i) restore protection benefits; (ii) limit negative effects on transboundary water resources; and(iii) conserve biodiversity in both natural and modified wetlands. Experience has demonstrated that initiatives aimed at wetland conservation and management must be recognized as a long term process that aims at building a strong knowledge base. Capacity for wetlands management must be built at all levels to address institutional sustainability, ownership, user right and access.

Chapter 3

Farmers' knowledge and perception of agricultural wetland management in Rwanda

Nabahungu, N.L. and Visser, S.M., 2011. Farmers' knowledge and perception of agricultural wetland management in Rwanda. Land Degradation and Development. DOI: 10.1002/ldr.1133

Farmers' knowledge and perception of agricultural wetland management in Rwanda

Abstract

Most of Rwanda's wetlands are being reclaimed under government schemes, with the aim of growing rice as the main crop. In the present study, information on farmers' knowledge and perceptions of agricultural wetland management was collected in Cyabayaga and Rugeramigozi wetlands. The two wetlands were selected as representatives for typical reclaimed wetland agriculture in Rwanda. They provide contrasts, in both environmental and social terms. Three tools were used to investigate farmers' knowledge and perception of agricultural wetland management: 1) household survey, 2) focus group discussions and 3) transect walk. The major constraints identified by farmers in the 2 wetlands were water shortage and lack of availability of improved seeds and high prices of fertilizers.The primary benefits from wetlands for farmers are income generation in Cyabayaga and food security in Rugeramigozi. The most commonly reported concern about the wetlands in the Cyabayaga and Rugerameragozi wetlands was that they are a source of malaria. Rice is an important crop in both wetlands, but whereas farmers in Cyabayaga wish to continue cultivating rice, Rugeramigozi farmers prefer to grow rice only after it has been tested for its adaptability. Farmers have sufficient knowledge on the causes and the potential solutions to overcome most constraints related to agricultural management. They know that soil suitability is closely related to relief. They classify soils by a number of criteria and choose crops accordingly. Any programme designed to address wetland management in the region will have to take account of farmers' knowledge and adopt a holistic view of wetland management.

3.1 Introduction

The land surface of Rwanda is 26388 km^2 and the country has a population of about9 million (NISR, 2008). The population density is with 380 persons km^{-2} one of the highest in Sub Saharan Africa. Rwanda is administratively divided into five provinces one of which includes Kigali City, 30 districts and 415 sectors (NISR, 2008). About 91% of the population lives and works in the rural sector with about 90% depending on agriculture for their livelihood. The agricultural sector is the backbone of the economy and contributes about 41% to the GDP and more than 72% to all exports (REMA, 2009). In most districts in Rwanda, intensive farming on hill-slopes has degraded land (Clay et al., 1998; Denny and Turyatunga, 1992). Research report soil losses 20 to 150 tons ha year^{-1} (Roose and Ndayizigiye, 1997) on 15 to 50% of slopes, and along with it declining soil fertility (Clay et al., 1998). Since the increased demand for agricultural products cannot be met solely by intensifying agriculture on these slopes, farmers are compelled to extend agriculture into more fragile environments such as even steeper hill slopes and wetlands.

The use of wetlands for agriculture is a relatively recent phenomenon in Rwanda, dating back to the start of 19th century. In the eastern part of Rwanda, the agricultural exploitation of wetland did not start until the 1960's. In most cases, wetland agriculture was a response to food and fodder shortages in the dry seasons, or to drought periods. The past kingdom and successive government policies have had a direct influence on wetland agricultural use. The use of wetlands has therefore been influenced more by political and socio-economic factors than by individual farmers. For example, from 1980 to 1994, wetland agriculture was encouraged to produce food to achieve self-sufficiency.

Currently the Rwandan government sees wetlands as providing an important niche for improving food security and income through the production of rice and other commodities. In the Rwandan context, "wetland" is defined as all lowlands and comprises the entire valley bottom, both the well-drained and wet areas. The total area of wetland in Rwanda is278536 ha (10.6% of the total land surface of Rwanda) (REMA, 2009). However, out of 148344ha under cultivation in 2010, only 5000 ha are official reclaimed often with a poor design and maintenance (Nabahungu and Visser, 2011b). The rest is unofficially reclaimed and a traditional farming system is practiced by farmers for food security.

In the past, agricultural and natural resource management development projects were often based on top-down transfer of expert knowledge from development agencies to the 'intended beneficiaries'. Farmers' reluctance to adapt new technologies was blamed on their ignorance, which could be overcome with a higher input of extension activities (Oudwater and Martin, 2003). It is becoming increasingly recognized that natural resource management is a complex process requiring full participation from different stakeholders. This is necessary, given that constraints to natural resource management require a broader management approach that considers not only biophysical aspects, but also farmers' knowledge, socio-economic aspects, and policy considerations. In this respect, only with farmers' participation, a successful practical approach to sustainable wetland management can be developed (Dixon, 2005). Furthermore, for development planning and interventions to be successful it is necessary to fit external technologies and strategies to the local environmental and cultural context (Niemeijer and Mazzucato, 2003). This requires scientists and development workers to develop a thorough understanding of local soil knowledge and land use practices in relation to the external technologies and development strategies they are promoting.

According to the law determining the use and management of marshlands in Rwanda, wetlands are publically owned, whereas the uplands are in private ownership (REMA, 2009). To cultivate wetlands, farmers have to obtain authorization from the district authorities. If they do not follow the cultivation protocol from the local government, they may forfeit their rights to cultivation. However, the farming system and the level of organization of the farmers cultivating the wetlands differ, depending on the degree of reclamation and the size of wetland (MINAGRI, 2002). Wetlands reclaimed by the public services or as part of agricultural projects have higher reclamation costs, partly due to the construction of required water storage, distribution, irrigation and drainage facilities (MINAGRI, 2002). Farmers are organized into cooperatives which fall under the aegis of a wetlands management committee. Farmers can cultivate in reclaimed wetlands under the condition that they implement the agriculture policy which consists of regionalization and intensification of crop production (GoR, 2005). The crops and the cropping systems are selected by the district or by the management committee. The small, unofficial reclaimed and traditional farmed wetlands are managed either by individuals or by families, and each farmer chooses which crops to plant. In cultivation and sowing periods, when high labour demand is observed, informal groups are formed in which farmers help each other in agriculture-related activities.

Official reclaimed wetlands are intensively used for single crop production, following government policy. Existing reports (Denny and Turyatunga, 1992; Lema, 1996; MINAGRI, 2002) however, indicate that these intensively managed wetlands have proved to be less sustainable in crop production compared to traditionally managed wetland. The intensive management has been applied without accommodating local peoples' knowledge. Therefore, the objective of this study was to investigate farmers' knowledge and perception of improved agricultural wetland management in Rwanda. The results can be used to improve wetland management in Rwanda.

3.2 Materials and methods

3.2.1 The research area

The Cyabayaga and Rugeramigozi wetlands (Figure 3.1) were selected as representatives for typical reclaimed wetland agriculture in Rwanda (MINAGRI, 2002). At both sites, the surrounding catchments are characterized by gentle hillsides gradually converging into wetlands. The village set up in the hillsides consists of mainly scattered households. Farmers in the catchment have fields both in hillside and wetlands. At both field sites farmers experience the decline of productivity of their land due to continuous cropping without adequate attention for soil fertility and, on the hillslopes, soil erosion.

The Cyabayaga wetland is located in Nyagatare district (1°22' 51.6" S, 30°17'07" E), in the Eastern Province of Rwanda. It is part of the eastern savanna agro-ecological zone lying about 1400m asl and has an area of 1080 ha. In 1978, the wetland was reclaimed for rice production. Before 1969 the Cyabayaga catchment was hunting zone. In 1970the hillsides were converted into settlement and cultivation areas. After the 1994, there was a new settlement of returned Rwandese from neighbouring countries e.g. Uganda.

The Rugeramigozi wetland is located in Muhanga District (02° 07’40’’ S, 29° 45’ 20’’E), in the Southern Province. It is located on the plateau agro-ecological zone of Rwanda at around 1650m asl and covers an area of 225 ha. After official reclamation in 1999-2000, the land was redistributed by the wetland cooperative. Since the beginning of the 19^{th} century until official reclamation for rice production, the wetland was cultivated only in the dry season (Season C) from June to September. Currently (2010) farmers do cultivate in the wetland throughout the year.

The annual range of rainfall is 1200-1400 mm in Rugeramigozi and 800-1000mm in Cyabayaga. The rainfall pattern in Rwanda is bimodal with the short, most important and reliable rains season from September to January (named Season A).The long rains season runs from mid-February to May (Season B) and has high intensity rainfall.

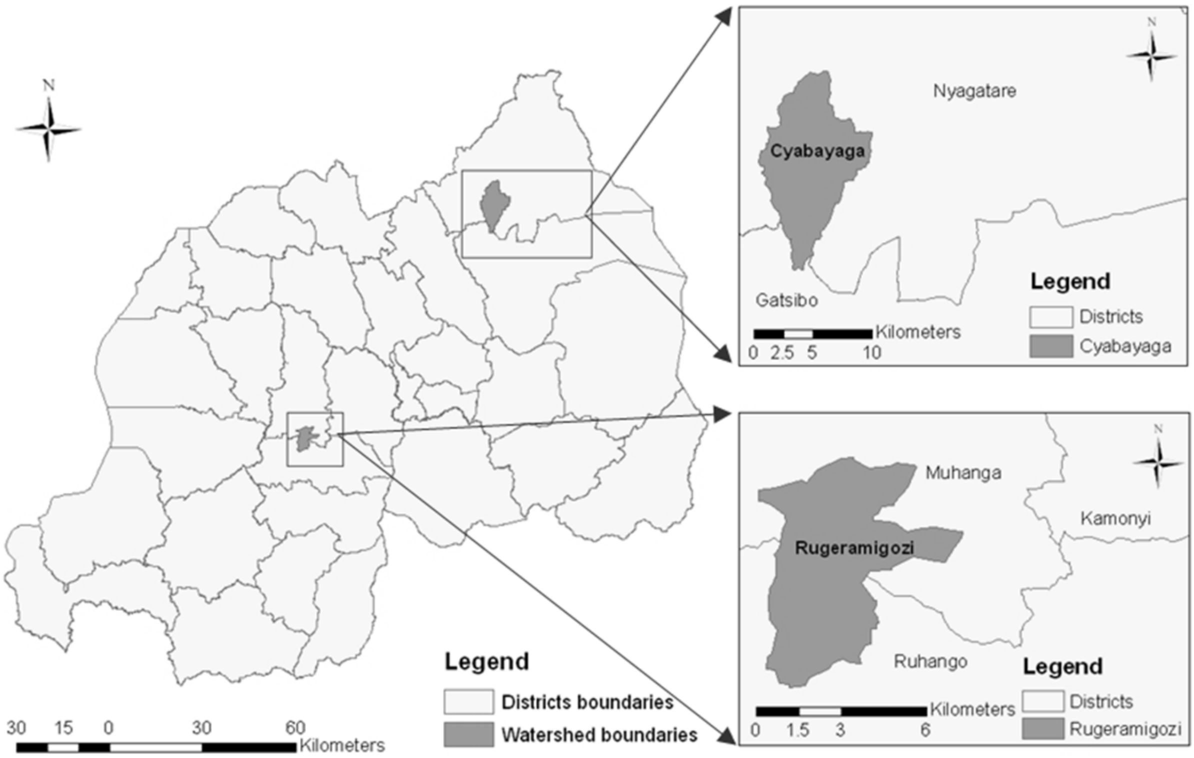


Figure 3.1. Location of Rugeramigozi, Southern Province and Cyabayaga, Eastern Province of Rwanda.

3.2.2 Farmers’ survey in Cyabayaga and Rugeramigozi

Field research on farmers’ knowledge and perception on wetland management was carried out in three main stages and involved both formal and informal survey methods, following the method of de Graaff (1996). The development agents present in the catchment and the chairpersons of the villages were the facilitators for focus group discussion and interviews.

Table 3.1. Characteristics of survey respondents in Rugeramigozi and Cyabayaga watersheds, Rwanda, 2007.

Households characteristics	Description	Location	
		Rugeramigozi (n=96)	Cyabayaga (n=157)
Head gender (%)	Men	70.0	80.8
	Women	30.0	19.2
Family size (n)		5.5	6.0
Education (%)	None	25.0	18.4
	Primary	61.4	72.2
	Secondary	13.6	7.7
	University	0.0	0.0
	others	0.0	1.7
Age group (%)	<18	4.7	0
	18-55	76.7	89.9
	>55	10.2	10.1
Marital status of the household head (%)	Single	21.5	11.2
	Married	60.0	74.8
	Divorced	0.0	1.4
	Widow	18.5	12.6

The first stage involved focus group discussions with key informants and selected farmers (seven men and seven women), with the aim to obtain general information and views about the use of wetlands in the catchment framework. Pair-wise comparison was used to rank the constraints in terms of their importance (Mowoet al., 2007). Farmers were requested to indicate the causes and proposed strategies for addressing 4 of the top ranked constraints. A checklist was set up during the preparatory stages of the focus group discussion to guide the discussion.

The formal household survey using pre-designed survey forms was conducted between July and December 2007. Farmers were randomly selected for the interview (using simple random sampling with replacement) from lists obtained from community leaders in the two wetlands in the catchment. Ninety-six farmers from Rugeramigozi and 157 from Cyabayaga were interviewed (Table 3.1), which ensured that at least 10% of farmer households were sampled in each site. When a farmer was unavailable or unwilling to be interviewed a substitute was selected. The household interview comprised both open-ended and closed questions. Issues of farmers' knowledge and perception of improved agricultural wetland management known to, or practiced by farmers, were put in open question format. Interviews were conducted by the principal author and trained field technician from ISAR (Institut des Sciences Agronomiques du Rwanda). A test survey was conducted with 15 farmers to evaluate the questionnaire, and based on these responses some minor modifications were made prior to conducting the full survey. The test survey period also permitted standardisation of the interview technique for all interviewers.

The third stage entailed doing a transect walk in each study area across the catchment, in order to obtain physical information and validate the information collected during the formal survey and focus group discussion. Each transect from the upland to the wetlands area was walked under the guidance of local farmers. The aim was to make a detailed description of the way the natural resources present along the routes are used in three niches: the uplands, the mid-slopes and the wetland area. The guides were elder farmers, 2 women and 2 men for each transect who had cropped in the area at least 10 years. The features recorded were grouped under soil types and their uses, water sources, crop production systems, livestock production systems (including type and source of fodder) and trees and shrubs. Constraints to the crop and livestock production and opportunities to address them were discussed and prioritized by the farmers in detail.

3.2.3 Data analysis

Data from focus group discussion, the four most important constraints were obtained using a pair-wise raking (Mowo et al., 2007). The statistical significance of the identified reasons of appreciation of wetland or not was evaluated by chi-squared method. This method compares the extent of differences and similarity between the two sites using the chi-squared (X^2) as the test statistics (Tenge et al., 2004). The use of wetlands before reclamation, current use and preferred crops and reasons behind the choice of different crops were explored using by means of cross tabulation. The statistical package used was SPSS 17.0 for Windows software. The field observations from the transect walks were used to complement the information from the survey and focus group discussion.

3.3 Results

3.3.1 Focus Group discussion

In the reclaimed wetlands, farmers are organized by an association and directed by a wetland management committee which, acting on advice from the district agricultural officer, stipulates the crops and the cropping systems. The farmer contribution to the cooperative is 2-3 US$ per block of 20 m x 30 m per year, which is used for wetland infrastructures maintenance.

The average number of plots per household was 5 in Rugeramigozi and 4 in Cyabayaga. The fields had an average size of 0.06 ha in Rugeramigozi and 0.35 ha in Cyabayaga. The fields were scattered at various distances from the house, each field has its own specific characteristics of fertility and form of tenancy.

Constraints, causes, effects and strategies

The constraints to improved wetland management were perceived by farmers in Cyabayaga and Rugeramigozi to be both internal and external to the areas. Farmers were well aware of the causes of the internal constraints and of strategies to overcome them. However, the farmers have limited knowledge about the off-site services which wetland offers, such as water supply to nearby towns (Muhanga is supplied by Rugeramigozi wetland).

The focus group discussion revealed that smallholder farmers in the target wetlands were affected by multiple constraints (Table 3.2). Constraints identified were prioritized by farmers through mutual consensus. The two major constraints identified by farmers in the 2 wetlands are water shortage and lack of availability of improved seeds and fertilizers (Table 3.2). Besides the two common constraints in the research area, in Cyabayaga wetland siltation and the lack of knowledge of the present cropping system were mentioned as other important issues. In Rugeramigozi, the acute problems mentioned included lack of trust of the association/cooperative committee, and soil fertility decline.

In Cyabayaga wetlands, water has become scarcer for about 1/3 of farmers for rice production during the cropping periods. This is particularly the case for farmers whose fields are located at the tail end of water channels. These results confirm the findings of previous research in Tanzania (Mwakalila, 2006) and in Rwanda (Kayiranga, 2006), which asserts that availability of water depends on the location of the field and soil type in wetlands. Fields located far from the main irrigation canal receive less water. In the Cyabayaga wetland, farmers suggested that siltation is the major cause of water shortage because it causes channels to become choked. Farmers who are near the reservoir have sufficient water, but those who are further away do not. This results in serious conflicts about the allocation of water in the planting periods.

In Rugeramigozi too, non-equitable distribution of available water was the major constraint amongst farmers (Table 3.2). Here, some fields experience water shortage, whereas others receive an excess of water. Farmers feel that the water is adequate but subject to technical difficulties related to poor wetland reclamation, eventually resulting in unreliable water flows.

Table 3.2. The most important production constraints, their perceived causes and farmers' strategies to overcome the constraints for agricultural management in Cyabayaga and Rugeramigozi wetlands, Rwanda.

	Constraint	Rank	Cause	Farmer's proposed strategy
Cyabayaga	Water shortage	1	-Inappropriate wetland levelling -High soil infiltration	-Increase dam capacity -Other crops when rice is inappropriate
	Lack of inputs	2	-Limited access to improved seeds -High price of fertilizers -Limited access to credit	-Make improved seed available -Improve policy on fertilizer prices -Improve access to credit facilities
	Siltation	3	-Silt transported by the river, -Lack of erosion control on hillside,	-Clean channels, -Terracing, -Plant grasses along contours
	Rice diseases	4	-Inappropriate cropping system -Limited access to improved seeds -Lack of knowledge	-Provision of resistant varieties, -Access to pesticide, legume crops in rotation with rice - strengthen capacity building
Rugeramigozi	Water	1	-Inappropriate wetland reclamation	-Change the cropping system
	Lack of input	2	-High prices of inputs -Lack of appropriate input -Fear to take a loan	-Improve price policy for inputs -Use improved seeds and fertilizers -Improve awareness of the importance of credit
	Lack of trust of association/co operative committee	3	-Associations headed by wealthy farmers -Misuse of community funds, -The interests of local authorities are protected	-Monitor and evaluate the actions of association committee
	Soil fertility decline	4	-Inherent low soil fertility, -Limited use of fertilizer -Lack of crop rotation	-Livestock for manure production, -Facilities to purchase fertilizers -Appropriate crop rotation

Continuous cultivation of rice in Cyabayaga wetland has led to problems with various pests and diseases. Diseases prevailed were rice blast (*Pyriculariaoryzae*), sheath rot and rice yellow mottle virus. Among the most dreadful diseases, rice blast was a major concern. Farmers reported several new diseases that have only recently appeared and they felt that almost none of the available rice varieties were completely resistant to pests and diseases. They said that they are willing to grow new disease-resistant varieties even if their yields are less than the current high-yielding varieties.

Long grains rice varieties (WAT 1395-B-24-2 and Kavamahanga) are grown in Cyabayaga whereas in Rugeramigozi short grains varieties are grown (ZhongGeng, Yun Keng and Yun Yin). Long grains rice is most preferred by farming producing for the market because of the high prices compared to the short grain rice varieties.

There are few micro finance institutions located within the two watersheds. These institutions are important sources of credit facilities. However, farmers find it quite difficult to acquire credit from these financial institutions ,because of bureaucratic procedures and pre-conditions. In Rugeramigozi, even though farmers have access to financial credit, they are reluctant to take out loans from the microfinance institutions. The reluctance to obtain the credit to purchase inputs is the result of previous failures of the rice crop: low yields left farmers unable to pay back the credit. The main strategies currently employed by farmers to enhance soil fertility in Rugeramigozi wetland include the use of organic manure, and the incorporation of weeds and crop residues during weeding and harvesting activities respectively. To overcome the lack of fertilizers, farmers keep cattle for manure production. Almost all farmers keep at least one type of livestock (chickens, rabbits, goats, pigs, cattle) ,but most can only afford to keep the smaller livestock. However, lack of skills for effective manure handling remains a concern.

Table 3.3. Primary reasons for respondents to appreciate or dislike wetlands in Cyabayaga and Rugeramigozi watersheds, Rwanda.

	Reasons	Cyabayaga (N=157)	Rugeramigozi (N=96)	Chi-squared	Significant level
Appreciation	Income (%)	32.6	16.8	7.7	**
	Food security (%)	29.3	70.0	41.5	***
	Water for livestock (%)	22.0	0	25.7	***
	Cultivating in dry season (%)	3.0	3.1	0.001	n.s
	Forage source for livestock (%)	13.1	10.0	0.5	n.s
Dislike	Malaria (%)	44.9	50.0	0.7	n.s
	Other human diseases (%)	1.4	9.3	11	***
	Livestock area lost for cropping (%)	26.7	2.7	22	***
	Fields flood (%)	12.0	30	12.7	***
	High labour required (%)	15.0	8.0	2.2	n.s

ns: not significant, ** significant at 0.01, *** significant at 0.001

3.3.2 Formal survey

Farmers' perceptions of the advantage and problems of wetlands

Table 3.3 presents an overview of the benefits and concerns of wetland farming as perceived by the farmers, per watershed. The most commonly reported concern about the wetlands in both sites was malaria (Table 3.3); McHugh et al. (2007) observed the same concerns in Ethiopia. A second common issue reported by 26.7% of farmers in Cyabayaga was the use of wetland for grazing. Concerning the grazing conditions in the wetlands, it was reported that it was easier to graze livestock in the wetlands in the past. Most of the changes are reported to have taken place around 2003 when the government expended wetland reclamation for rice cultivation. The wetland is communal land: once reclaimed, however, grazing in the area is prohibited to prevent the destruction of engineering structures for irrigation and drainage. The respondents were concerned that the reclamation of the remaining part for crop production would reduce the grazing area. The second issue causing concern to respondents in Rugeramigozi was the risk of flooding in April and May, which results in large (30%) harvest losses. Although, 22.0% of farmers in Cyabayaga appreciate the wetland because it is a source of water for livestock, in Rugeramigozi the farmers do not use wetland as a source of water for their livestock. They apply zero grazing, and rely on springs and rainfall harvested from roofs to meet their domestic and cattle needs for water. However, according to the focus group discussion, the number of functional springs in Rugeramigozi has decreased: from over 10 prior to 1994 to 7 in 2010. Despite the abovementioned concerns, only 1% (Cyabayaga) and 8% (Rugeramigozi) of respondents reported that they disliked the presence of wetlands in their watershed.

Agricultural use of wetland

Table 3.4 shows the use of wetlands before reclamation, and the cultivated and preferred crops in the Cyabayaga and Rugeramigozi wetlands. Rice has not been adopted by the great majority of farmers in Rugeramigozi since its introduction by ISAR, with the exception of local short grains varieties (ZhongGeng, Yun Keng and Yun Yin) (ISAR, 2005). These varieties generally have low yield and relatively a low market value compared to long grains varieties found in Cyabayaga wetland. Some farmers in Rugeramigozi recognize rice as a source of income, but claim that the improved long grains varieties introduced by ISAR were not sufficiently adapted to their wetland. The low adaptability of improved long grain varieties could be related to the high altitude and poor soil fertility found in Rugeramigozi.

Table 3.4. Use of wetland before reclamation, and current situation and preferred crops in Cyabayaga and Rugeramigozi wetlands, Rwanda.

Crops/land use	Cyabayaga (N=157)			Rugeramigozi (N=96)		
	Before reclamation	Current	Farmers' preferences	Before reclamation	Current	Farmers' preferences
Rice (%)	0.8	78.6	71.1	0.0	56.1	16.4
Maize (%)	0.9	10.4	12.1	10.0	13.1	28.9
Bean (%)	0.2	4.2	5.2	30.8	20.2	32.8
Sorghum (%)	0.6	2.7	3.5	16.2	6.0	5.2
Vegetables (%)	0.0	2.2	5.2	9.5	3.6	10.5
Soybean (%)	0.2	1.1	2.0	3.5	1.0	2.2
Sweet potatoes (%)	0	0.8	0.9	30.0	0.0	4.0
Forest (%)	97.3	0.0	0.0	0.0	0.0	0.0

Farmers' production objectives

The farmers' reasons to cultivate specific crops and their reasons to prefer certain crops are shown in Table 3.5. The main reason for farmers in Rugeramigozi to grow rice was government policy (55%). Because rice can generate more income, even more farmers would prefer to grow rice instead of other crops (59.7%), if the varieties that are adapted to the local conditions were available. Beans, maize and sorghum were generally grown for household consumption. Relatively small percentages of farmers produced sufficient surpluses of these crops for income generation. Vegetables are more market oriented: 71.4% of the farmers grew vegetables for income generation. According to the farmers, the only concern with vegetables is that they are not easy to store, which results in lower prices around harvest time.

Farmers considered that beans and maize have a market potential. Currently the production is low and mainly intended for domestic consumption. Wealthy farmers conserve dry beans and wait until the market price is high, in order to maximize income. Contrary to official recommendations which advocate consuming maize that has been dried or milled, farmers in Rugeramigozi sell green roasted maize near their fields. The farmers confirmed that maize sold as grain fetched higher prices.

In reclaimed wetlands, farmers were obliged to grow rice. At both sites it was found that rice is preferred over other crops. This is because of the high income it can generate compared to other crops in Rwanda, but only when an adapted variety is grown. Preference for rice has also been observed in Rusuli Rwamuginga wetland in Rwanda (Mbarushimana and Nsabimana, 2008).

Table 3.5. Farmers' primary reasons for the choice of current crops and their preferred crops in Cyabayaga and Rugeramigozi wetlands, Rwanda.

		Cyabayaga (N=157)				Rugeramigozi (N=96)			
		Policy	Adaptation	Income	Food security	Policy	Adaptation	Income	Food security
Current	Rice (%)	38.4	27.4	25.2	7.2	55.0	5.4	20.2	19.4
	Maize (%)	12.8	7.6	18.2	62.1	12.0	18.4	28.2	41.4
	Beans (%)	3.7	3.7	3.7	88.9	3.0	14.4	13.7	68.9
	Sorghum (%)	0	23.5	17.6	58.8	0	23.6	28.4	48.0
	Vegetables (%)	7.1	7.1	71.4	14.3	5.0	9.2	71.4	14.3
Preferred	Rice (%)	-	35.1	39.0	24.7	-	15.2	59.7	24.1
	Maize (%)	-	27.3	24.2	45.5	-	27.0	34.2	35.8
	Beans (%)	-	35.6	42.2	15.7	-	25.8	32.0	35.7
	Sorghum (%)	-	22.7	68.2	4.5	-	23.2	48.2	24.6
	Vegetables (%)	-	13.8	82.8	3.4	-	23.7	62.9	13.4

3.3.3 Transect walks

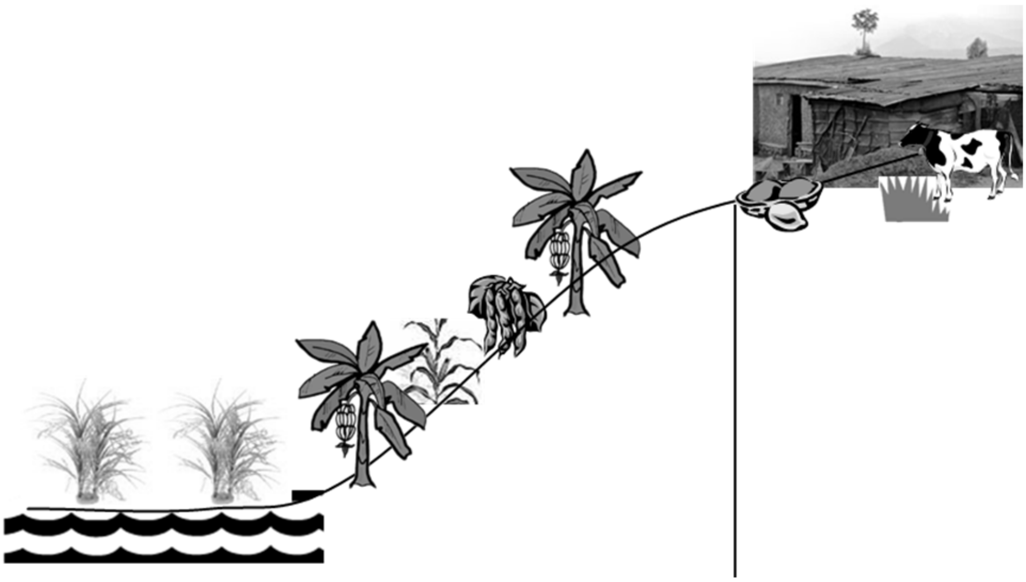
The features recorded during the transect walks were grouped under soil types and their uses, water sources, crop production systems, and livestock production systems (including type and source of fodder). Through transect walks; several opportunities to address some of the constraints present in the watershed were identified. Figure 3.2 and 3.3 show the soil characteristics and agricultural management related parameters recorded and opportunities and constraints identified by farmers along transect walk in Cyabayaga and Rugeramigozi catchments respectively.

Farmers know that soil fertility and consequently soil types are closely related to relief, expressed as the form of the slope (convex or concave) or position on the slope. On eroded hilltops, on steep slopes and convex slopes, the dominant soils are shallow and stony and are called *Uresenyi*, on the flat tops of hills (plateaux), concave slopes and at the foot of hills, deep, fine-textured soils called *Urunombe*, prevail. In the valley bottoms are dark or greyish colluvial and alluvial soils (*Urubumba*), generally fine–textured; in wetland, other types of soils can be found, such as peat soils (*Nyiramugengeri*).

Farmers know that soil management has to be adapted to the type of soil, i.e., heavy loamy or clayey soils need to be treated differently from light sandy soils. The key factor is the content of organic matter as major source of plant nutrients, and consequently organic manuring, especially farmyard manure, is regarded as the principal soil-improving practice. Although the farmers prefer farmyard manure, compost is also used as organic amendment by the poor farmers with few or no livestock, or on remote fields. Farmers used weeds, crop residues (e.g. maize stover, banana leaves, sweet potato vines) and household wastes to make compost. The allocation of organic or inorganic fertilizer to fields is based on soil texture and the nature of the crop to be grown. In wetlands, urea is applied on rice cropping systems both in Cyabayaga and Rugeramigozi. But the urea was used only by 10% of farmers in Rugeramigozi and at a low rate of 50 kg ha^{-1}compared to the recommended 100 kg ha^{-1}. In Cyabayaga 68% of farmers were using DAP and urea at the rate of 100 kg ha^{-1} each on rice. Near the homestead and on relatively fertile soils, farmyard manure is applied to demanding crops: bananas, maize and vegetables. The rate used were between 2-4 t ha^{-1} of dry matter on banana intercropping with beans, 0.8-3 t ha^{-1} on maize and vegetables in both sites. The rate used were below the recommended rate of 10 tons of FYM (dry matter) per ha (Rutungaet al., 1998). Compost is used on remote fields, where crops such as sweet potatoes, cassava and groundnuts are grown. Farmers are aware that using organic matter (compost or farmyard manure) improves soil productivity and also soil water retention and thus can help to reduce the effect of shortage of rainfall. According to the farmers, since the total organic matter production is unable to supply the needs of all the fields, more than half of fields are never fertilized especially the remote fields on hillsides.

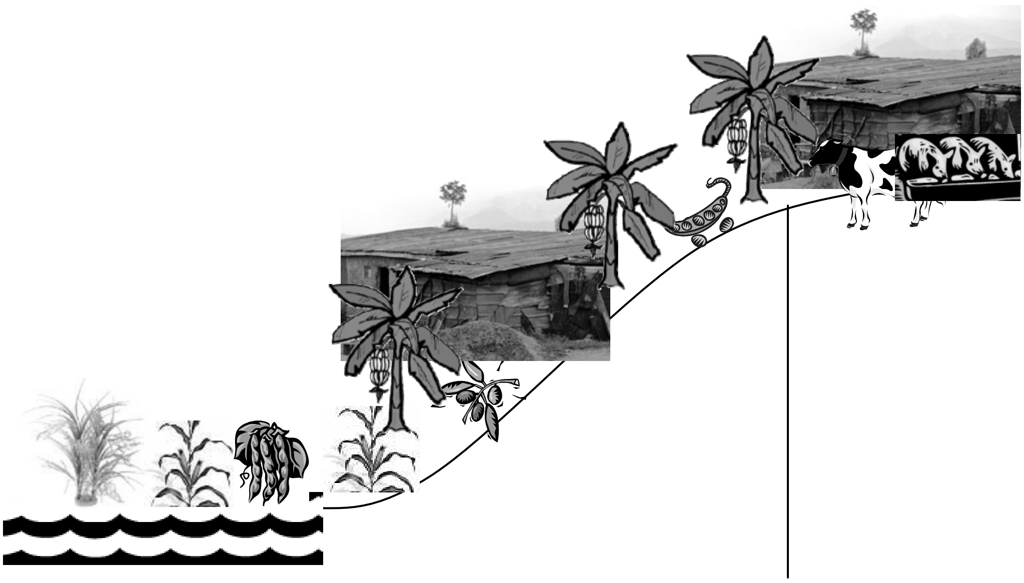
Farmers match cropping systems with soil type and their positions. For shallow soils (depth <50cm) e.g. *Mugugu, Urusenyi*, they sow maize intercropped with beans and vegetables after the first rains, because these soils have a low capacity to retain water. For the dark clay soils (*inombey'umukara*) they sow maize intercropped with beans after the second rains, while for the red clay soils (*inombeitukura*), sweet potatoes and cassava are sown after the third rain. In wetland, they sow rice, beans, maize, sorghum and vegetables2 to 3 weeks before or after the rain seasons because water limitation is not relatively a critical constraint.

On hillsides in Rugeramigozi, soil conservation and fodder production were highly ranked opportunities (Figure 3.2) while on the equivalent slope positions in Cyabayaga, important opportunities (Figure 3.3) were improved dairy cattle production, mixed farming and increasing the production of sweet potato, cassava and groundnuts. On the lower slopes existing opportunities include availability of water during the dry seasons, and a surplus of rice straw for use as livestock feed. With regard to domestic and livestock water supply, farmers' innovations include harvesting rainwater from roofs (domestic) and diversion of ephemeral streams using traditional water harvesting systems. This system could easily be improved at low cost, to increase the amount of water and prolong its availability.



Niche	Wetland	Midland	Upland
Soils	- Clay loam - Urea on rice production - No slope	- Sandy loam/sandy-clay - Farmyard manure - Steep slope (>10%)	- Sandy-gravelly soils - Farmyard manure - Gentle slope (<8%)
Agricultural system	- Rice mono cropping (78%) - Crop rotation (22%)	- Mixed cropping - Zero grazing	- Scattered farm housing - Mixed cropping - Semi-zero grazing
Crops	- Rice, Beans, Maize, Vegetables	- Banana, sorghum, cassava, fruit trees, arrowroots, sweet potato, groundnuts, peas, maize	- Beans, peas, groundnut, sorghum, maize
Livestock	-	- Only fodder supply	- Cows, goats pigs, ducks, chickens
Water sources	- Dam and river	- Small rainwater-fed ponds	- Small rain water harvesting ponds used for dairy farmers, - Small scale roof rain water harvesting
Fodder	- Crop residues, *Tripsacum laxum*	- *Pinnesetum purpureum, Setariaanceps*	- *Pinnesetum purpureum, Dracaena afromontana, Tripsacum laxum,*crop residues
Constraints	- Water for rice production - Lack of improved seeds, - Lack of fertilizer	- Striga - Low rainfall - Low soil fertility - Cassava mosaic disease - Cow diseases	- Striga - Low soil fertility - Crop pest's - Low rainfall - Cattle diseases, especially foot and mouth disease
Opportunities	- Use rice straw fodder - Improve crop irrigation	- Mixed farming - Improved rain water harvesting - Soil conservation measures	- Improved dairy cattle production - Rainwater harvesting techniques

Figure 3.2. Soil characteristics and agricultural management related parameters recorded and opportunities and constraints identified by farmers along transect walk in the Cyabayaga catchment, December 2007, Rwanda.



Niche	Wetland	Midland/Slope	Upland
Soils	- Clay soil - High iron reduction - With manure high production	- Deep lateritic soil - High response to manure - Steep slopes (>15%)	- Gravel/ lateritic soil - Dry immediately after rain - Gentle slopes (<10%)
Agricultural system	- Crop rotation (48%) - Rice mono cropping (52%)	- Mixed cropping - Zero grazing	- Mixed cropping - Zero grazing
Crops	- Rice, beans, maize, soybean, vegetables	- Banana, coffee, beans, fruit trees, soybean, peas, sweet potatoes, cassava, maize	- Banana, coffee, beans, soybean, fruit trees, peas, sweet potatoes, cassava, maize
Livestock	-	- Goats, poultry, pigs cows, bees, rabbits	- Pigs, cows, poultry, rabbits
Water sources	- Small stream - Spring water	- Small ponds	-
Fodder	- Crop residues, *Tripsacum laxum*	- *Pinnesetum purpureum, Stariaanceps*	- *Pinnesetum purpureum, Dracaena afromontana, Staria anceps*, crop residues
Constraints	- Poor water distribution	- Land shortage - Severe soil erosion - Livestock and crop diseases - Low fertility - Lack of fodder production - Lack of agro-forestry species	- Land shortage - Livestock and crop diseases - Lack of fodder - Lack of agro-forestry species
Opportunities	- Access to water - Crop residues - Cut and carry fodder for cows	- Composting - Soil conservation measures - Fodder production	- Composting - Soil conservation measures - Fodder production

Figure 3.3. Soil characteristics and agricultural management related parameters recorded and opportunities and constraints identified by farmers along transect walk in the Rugeramigozi catchment, December 2007, Rwanda.

There were two main reasons perceived by the farmers for the declining productivity of their land: continual cropping without adequate attention to soil fertility (over-cultivation) and soil erosion. The poor status of soil fertility in wetlands was confirmed by laboratory analysis (Nabahungu and Visser, 2011b, ch 4). Soils of Rugeramigozi wetland were very poor compared to Cyabayaga wetland. In Rugeramigozi, pH in water (4.4) was strongly acidic when Bray 1 P (7.5 mgkg^{-1}) and total nitrogen (0.11%) were very low. In Cyabayaga pH in water (5.7) was slightly acidic when Bray 1 P (29.7 mg kg^{-1}) and total nitrogen (0.38%) were in the medium level.

Over-cultivation tends to occur in wetlands and upland on relatively gentle slopes (<10%), since these are the lands that farmers most often cultivate; by contrast, fields suffering from soil erosion problems tend to be those situated on midway up the hillside(steep slopes>15%). Farmers knew that the rate of soil loss is related to the soil fertility and that this determines the potential crop yield at any position in the landscape. The majority of farmers perceived that steep and very steep slopes were the landscape units with the highest risk of soil erosion and poorest soil fertility, and hence with low crop production. Because of the negligible soil loss and year-round moisture content in wetlands, the potential crop yield of these areas tended to be high (Kangalawe and Liwenga, 2005).

Based on farmers' responses to the question on available solutions for reversing the declining trends in soil fertility and hence improving agricultural productivity, three main points emerged; (i) mitigating soil erosion on hillside (ii) use of indigenous nutrient resources like farmyard manure, compost, green manure (iii) increasing farmers' capacity in soil conservation and manure handling and use. Farmers noted that loss of topsoil due to erosion can be mitigated by applying different soil conservation techniques. Anti-erosive ditches, grass strips and hedgerows are the dominant approach to control soil loss in both sites. Bench terraces have been constructed in Rugeramigozi trough a Germany project ''Agro Action Allemande''. Such measures will reduce siltation of the adjoining cultivated wetland. The farmers pointed out the use of indigenous nutrient resources as an important opportunity for soil fertility management.

3.4 Discussion and conclusion

Although examples of innovation in wetlands are generally less common than those for natural resource management in the uplands in Rwanda, the capacity within communities to solve problems and adapt to new situations clearly exists to a larger extent than was previously acknowledged (Nabahungu and Visser, 2011b, ch 4). Several participatory approaches have been developed to involve farmers in an interdisciplinary approach to agricultural research (Chambers et al., 1989; van de Fliert and Braun, 2002). These approaches pay greater attention to actual farming practices, farmers' needs and farmers' knowledge (Oudwater and Martin, 2003). The ingenuity of Rwandan farmers has also been recognized by the government, particularly in its efforts to promote popular participation in development planning, known in Kinyarwanda(the national language of Rwanda) as *Ubudehe mu kurwanyaubukene*. In a report on the pilot programme of the "Ubudehe", the government acknowledges that, "there is sometimes a tendency to underestimate the abilities of illiterate peasants to analyze what is going on around them and their ability to implement solutions"(Republic of Rwanda, undated).

Among the constraints mentioned by the farmers, soil suitability and lack of improved seeds and high prices of fertilizers were perceived as acute. Soil suitability was related to many parameters which cause yield variability, such as water availability, and infiltration rate in wetlands. Rice diseases were mentioned as another important constraint in Cyabayaga wetland. The results also revealed that water management, fertilizer application method and disease controls are relevant for reducing the yield gap; this is consistent with other research findings in Rwanda (Kayiranga, 2006).

In Rwanda, wetland is owned by local government. This situation has a potentially negative impact on land management, because farmers won't invest much in their fields as they are not full owners.

Furthermore, the multi-resource characteristic wetlands influence the structure of resource-tenure and management regimes. Wetlands face huge demands for a multitude of uses and functions which often results in conflict between different users (Adger and Luttrell, 2000). The inherent nature of wetland resources invites such friction but often the institutional set-up exacerbates these conflict situations and is inadequate to deal with them.

Farmers in Rugeramigozi felt that they had little or no influence on the policies of their cooperatives. This may indicate an authoritative style of management where decisions are often taken without member participation or consultation. Members also felt powerless to change management. Although farmer led cooperatives can provide numerous benefits to members (Ortmann and King, 2007), according to Akwabi-Ameyaw (1997) these cooperatives have often not been successful in Africa because of problems in holding management accountable to the members, leading to financial irregularities in management.

A household in Rwanda has around 4 to 6 small plots scattered at various distances from the house; it is difficult to improve the management of scattered plots. It has been shown that fragmentation is not always related to land scarcity (Nabahungu and Visser, 2011b). In general a Rwandan farmer will actively try to access land in different eco-niches (e.g. valley bottoms and at higher altitudes), in order to benefit from differences in rainfall availability and soil retention characteristics (Balasubramanian and Egli, 1986). Consolidation of fragmented land is regarded by government (GoR, 2005) as a technique that will optimize production in the sector. However, Blarel et al. (1992) noted that consolidation policies are unlikely to increase land productivity significantly. For Rwanda, Blarel et al. (1992) favours field fragmentation, which, he argues, takes advantage of complementarities between crops, variations in soil types and differences in micro-climate.

The results of this study also demonstrate the importance of wetland for improving the socio-economic conditions of farmers living in the catchment. According to Nabahungu and Visser (2011b), the contribution of wetland cultivation was 74% ($ 1901 U.S.) in Cyabayaga and 24% ($ 84 U.S.) in Rugeramigozi of total cultivation gross margin per household per year. The residents of the Cyabayaga and Rugeramigozi watersheds generally appreciate the presence of the wetlands in their proximity, despite a few concerns (e.g. malaria risk) and constraints related to wetland productivity. This conclusion agrees with the findings concerning malaria as reported by McHugh *et al*. (2007) during the wetland assessment in Ethiopia. Technologies that enhance productivity and adaptability should be introduced, as a way of increasing productivity. The new technologies will be more easily introduced and assessed if the approaches will be built on existing indigenous technical knowledge, and an understanding of local problem solving, experimentation and innovation. According to Martin and Sherington (1997), there is much to be learnt from the interaction between farmers' research and formal research, because participatory research can draw on both indigenous and scientific knowledge systems. One manifestation of indigenous knowledge is in farmers' experimentation and technology adaptation. Obviously, the wetlands have much promise for agriculture and other uses. A delicate balance must be struck between using the rich wetlands resources for agriculture and for other uses (Dixon, 2002; Umoh, 2008).

The finding that profitability of rice has a positive effect on farmers' preferences in Rwanda is consistent with expectations. For example, Nabahungu and Visser (2011b, ch 4) found that rice in Cyabayaga was the largest contributor to household income on average of $ 1045 U.S. per household per season. Profit is a particularly important element of self-interest. In this context, profitable means that a new farming system is economically superior to the previous farming system. It is not sufficient for it to generate benefit by reducing input costs; it must also cover opportunity costs – the profits from alternative methods of resource use which must be foregone in order to use the resources in the new way (Pannell, 1999). Thus, profitability was necessary for favourable perceptions in the medium to long term for rice in Cyabayaga.

We found that transect walks yielded the most detail on farmers' knowledge of the soil, as the visual observations could be closely linked to farmers' management practices. Several authors have highlighted the importance of field visits for gaining more details on farmers' categories of soil (Kundiriet al., 1997; Brimingham, 1998). The local classification system in Rwanda is based on criteria influencing the use and productivity of soils (Habarurema and Steiner, 1997). Though farmers are interested in soil productivity and appropriate management practices, they take only the topsoil or the arable layer into account (Habarurema and Steiner, 1997). In addition, the farmers' classification is based on local soil classification and the farmers' objectives. Using the farmers' vernacular names can facilitate exchange between farmers, researchers and extension agents. In the two agro-ecological zones we studied, situated in different provinces, the farmers used the same names for the soils. The farmers' soil knowledge is also in agreement with findings reported by Habarurema and Steiner (1997) and Steiner (1998) on farmers in Rwanda, who associated soil suitability with slope position.

Poor production due to small fields and low inputs may explain a considerable part of the strong subsistence production – orientation found in Rugeramigozi compared to Cyabayaga (Table 3.3) ($P<0.001$). Both, higher gross margins and higher sustainability can be attained through higher use of external inputs. However, a transition to more sustainable production technologies is more likely when the risk, associated with growing certain high-value crops is reduced. This can be realised e.g. through the introduction of varieties which are adapted, high yielding and less prone to diseases, and the enhancement of economic incentives, such as well-developed input and output markets, for example for inorganic fertilizer. Berkhout et al. (2010) argued that households with smaller land holdings cannot afford strong variations in production, as that would threaten food security. According to Adesina (1996), one of the main factors that influence farmers' use of fertilizer in Côte d'Ivoire is farm size. It has been reported that larger farms are more likely to adopt innovations compared to small farms due to either economies of scale effects or preferential access to input and credit (Polson and Spencer, 1991).

It should be pointed out that the use of a small quantity and low quality organic manure alone, as it is practiced in Rugeramigozi, cannot provide enough nutrients to reach the yield levels which are desired to feed a high and ever increasing population. Farmers should therefore be provided with skills to optimize manure use to increase productivity per unit area especially for those crops with high market value like rice and vegetables. With increased income farmers should gradually move from using organic sources alone to blending these sources with inorganic fertilizers.

It can be concluded that when searching for improved wetland management, engineers, scientists and extensionists need to make use of farmers' knowledge of improved wetland management, work more closely together with them and offer them a range of crops and flexible soil management recommendations. Giving flexible extension recommendations and relying on farmers' location-specific knowledge and perception will help both to create trust and to assist farmers in optimizing the use of their natural resource management.

Chapter 4

Contribution of wetland agriculture to farmers' livelihood in Rwanda

Nabahungu, N.L. and Visser, S.M., 2011. Contribution of wetland agriculture to farmer's livelihood in Rwanda. Ecological Economics 71: 4-12.

Contribution of wetland agriculture to farmers' livelihood in Rwanda

Abstract

This study analyses factors that contribute to the livelihood of smallholder farmers living in the vicinity of the Cyabayaga and Rugeramigozi wetlands. Three tools were used: 1) focus group discussion, 2) formal surveys and 3) Monitoring for Quality Improvement (MONQI). Farming systems in wetlands and on hillsides differ. Level of education, resource availability, land ownership and location have an important impact on the location and type of farming systems practiced by households. The dependency of households on wetlands varies between sites. Field size, status of soil fertility and input use are also key factors determining the level of contribution that wetland agriculture makes to farmers' livelihood. In Cyabayaga, the per household per year contribution of wetland cultivation to gross margin (GM) was 74% ($ 1901 U.S.) compared to 24% ($ 84 U.S.) in Rugeramigozi. The rice in Cyabayaga was the largest contributor to household income providing on average $ 1045 per household per season. Vegetables cultivated in the dry season in Rugeramigozi have high potential as cash crops. Poor maintenance of drainage and irrigation channels as well as inappropriate cropping systems in wetlands can undermine sustainability and have repercussions for the livelihoods of farmers dependent on agricultural wetlands.

4.1 Introduction

Wetlands can be considered to be the world's most productive ecosystems. Wetlands have been described as ''the kidneys of the landscape'' because of the functions they perform in the hydrological and chemical cycles, and as ''biological supermarkets'' because of the extensive food webs and rich biodiversity they support (Ellison, 2004). Their intrinsic hydrological processes buffer against extremes such as droughts and flooding. During rainy periods, wetlands absorb water and therefore reduce flood risks. In the dry season wetlands gradually release their water and thus ensure water is available even in the dry periods. From an agricultural point of view, when properly used, wetlands have great agricultural potential (Kangalawe and Liwenga, 2005). Silvius et al. (2000) state that a significant proportion of people in developing countries depend upon the use of wetland resources in one way or another for their livelihoods. Several studies in southern and eastern Africa have shown that wetlands and their surrounding catchments support rural livelihood through provision of a large range of natural resources such as reed, fresh water, vegetables and wildlife (Turpie, 2000; McCartney and van Koppen, 2004; Masiyandima et al., 2004). Despite the value and importance of these services for many people, wetlands are, globally, among the most threatened ecosystems on earth. This threat comes especially from the impacts of agriculture and water management in the wetland areas (Falkenmark et al., 2007; Finlayson, 2007). This paper reports on the interaction of wetland use and farmer livelihood in Rwanda to identify and understand current threats to wetland ecosystems, and opportunities for increased sustainability of both wetland use and farmer livelihood.

Sustainable use of wetlands is defined by the Ramsar Convention (Ramsar, 2000) as "human use of a wetland so that it may yield the greatest continuous benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations". This definition is based on the concept that human use of wetlands is possible without endangering the long term integrity of the wetland ecosystem.

In Sub-Saharan Africa, a range of socio-economically important products and services, linked to the hydrological regime of wetlands, has been used for generations (Dixon and Wood, 2003). Most wetlands are critical sources of drinking water, of craft and building materials (e.g. reeds and clay) and of medicinal plants. Apart from harvesting and processing the present natural resources, wetland-use also includes cultivation and livestock grazing and watering. Wetland agriculture is often a major economic pursuit among rural communities; since they provide suitable cultivation conditions for a range of crops such as rice, maize and various vegetables (Adams, 1993). In many parts of eastern and central Africa where annual rainfall is high, drainage regimes, which balance water loss with water retention, are an integral part of the agricultural exploitation of wetlands. In some cases three crops per year can be grown under wetland conditions, therefore making wetlands a significant factor in food security and income generation (Wood, 1996). The use of wetlands by rural people and the resulting contribution to their economic situations varies greatly depending on the natural setting of the wetland, the socio-economic situation of the community and household, and the national, historical and political context (Morardet and Tchamba, 2005).

In Rwanda many rural households face food insecurity and poverty, therefore wetland goods and services are an important contributing factor to people's livelihoods (World Bank, 2005). In particular, the conversion of wetlands to agricultural production area has increased rapidly over the last decades due to the acute scarcity of agricultural land(REMA, 2009). The government supports wetland development with the aim to boost agriculture, revitalize the rural economy and reduce poverty (Kanyarukiga and Ngarambe, 1998). However, an assessment conducted by the government of Rwanda(RSSP, 2001)showed that the performance of some farmed wetlands was unsatisfactory and conversion has resulted in ecological and environmental damage that outweighs the value of the increased agricultural output (MINAGRI, 2002). Furthermore, the study concluded that, out of 5000 ha reclaimed, including water control works enabling both irrigation and drainage; 4000 ha were found to be in need of rehabilitation. Similar in Tanzania, Lema (1996) reports that traditional and sustainable forms of wetland cultivation are being replaced by intensive use regimes that are unlikely to be sustainable given the gradual degradation of resources. In this situation, care is needed because inappropriate use of wetlands undermines long term benefits. Inappropriate development of wetlands often leads to a loss in natural capital, deleterious environmental impacts and harmful consequences to people's livelihoods (MA, 2005b).

The aim of this study is to diagnose and analyse the present use of wetlands and their contribution to the farmers' livelihood in the Southern and Eastern provinces of Rwanda. In this paper qualitative and quantitative information on wetland agriculture are provided to guide decision making about wetland rehabilitation and evaluate whether new wetland reclamation is justified in Rwanda as well as in other areas within the region.

4.2 Material and Methods

4.2.1 Research area

The Cyabayaga and Rugeramigozi wetlands (Figure 3.1) were selected as representatives of typical wetland agriculture in Rwanda (MINAGRI, 2002). At both sites, the surrounding catchments are characterized by gentle hillsides gradually converging into wetlands. The villages located on the hillsides consist of mainly scattered households. Farmers in the catchment have fields in both hillside and wetland locations. Farmers in both study areas experience a decline in the productivity of their land due to over-cultivation and soil erosion on hillslope (Nabahungu and Visser, 2011a, ch 3).

The Cyabayaga wetland is located in the Nyagatare district (1°22' 51.6" S, 30°17'07" E), Eastern Province of Rwanda. It is part of the eastern savannah agro-ecological zone lying about 1400m asl and has an area of 1080 ha. Before 1969 the Cyabayaga catchment was a hunting zone. In 1970the hillsides were converted into settlement and cultivation areas. In 1978, the wetland was reclaimed for rice production. After 1994, a new settlement of returned Rwandese from neighbouring countries, e.g. Uganda, was established here.

The Rugeramigozi wetland is located in the Muhanga District (02° 07'40'' S, 29° 45' 20''E), Southern Province. It is located on the plateau agro-ecological zone of Rwanda at approximately 1650m asl, and covers an area of 225 ha. After official reclamation in 1999-2000, the land was redistributed by the wetland cooperative. Since the beginning of the 19th century until official reclamation, the wetland was cultivated only in the dry season (Season C) from June to September. Presently farmers practice cultivation of the wetland throughout the year.

The annual range of rainfall is 1200mm-1400mm in Rugeramigozi and 800-1000mm in Cyabayaga. The rainfall pattern in Rwanda is bimodal with the short, most important and reliable rains season from September to January (Season A). The long rains season runs from mid-February to May (Season B) and has high intensity rainfall.

4.2.2 Methodology

To determine the contribution of wetlands to farmers' livelihood, socio-economic information on agricultural management and production systems and household characteristics was required. Three socio-economic tools were used in this research; Participatory Rural Appraisal (PRA), a formal survey and the Monitoring for Quality Improvement (MONQI) toolbox. The PRA provided background information on the agricultural management and production system. The PRA and the formal survey provided qualitative and quantitative data on household characteristics and the MONQI toolbox was used to obtain detailed information on financial indicators at cropping activity level, niche (wetland versus hillside) level and household level.

The development agencies that work in the catchment and the chairpersons of the villages were the facilitators for focus group discussion, organised for the PRA and interviews. The focus group discussions with selected farmers (elders and leaders)in July 2007 were organised as a means to gain qualitative insight into wetland use in general. A checklist was set up during the preparatory stages of the focus group discussion to guide the discussion. Participatory wealth ranking was implemented to delineate wealth classes and categorise household diversity. For ease of categorization by key informants in the study sites the income rankings were grouped into three main Resource Group classes: poor, moderate and rich

The formal household survey using pre-designed survey forms was conducted between July and December 2007. Farmers were randomly selected for the interview (using simple random sampling with replacement) from lists obtained from community leaders in the two wetlands in the catchment. Ninety-six farmers from Rugeramigozi and 157 from Cyabayaga were interviewed. When a farmer was unavailable or unwilling to be interviewed a substitute was selected. The household interview was comprised of both open-ended and closed questions. Interviews were conducted by the principal author and trained field technicians from ISAR (Institut des Sciences Agronomiques du Rwanda). Based on the responses to a test survey conducted with 15 farmers to evaluate the questionnaire, some minor modifications were made prior to conducting the full survey. The test survey period also permitted standardisation of the interview technique for all interviewers.

Detailed information on financial indicators at activity level, niche (wetland versus hillside) level and farmer level were collected using MONQI (van Beek et al., 2009). MONQI is a methodology for monitoring management and performance of small scale farming systems world-wide (www.monqi.org). MONQI is dedicated to the monitoring of agricultural systems in the tropics with the aim of improving the quality of farm management, crop production, quality of production, living standards and living environment (van Beek et al., 2009). The criteria used during PRA to identify farmers' resource groups were presented to the key informants prior to the interviews to obtain a list of 9 poor, 9 moderately poor and 9 rich households in each study site. A subsample of 27 farmers for each site was interviewed in depth about their farm management practices using the MONQI standardized questionnaire. Interviews were performed a total of six times, at the start and end of each cropping season corresponding with the bimodal rainfall pattern in

Rwanda (seasons A and B) and the dry season in wetland(season C). Equivalence between measurement units used by local people and standard units were estimated through direct field observation and measurements.

4.2.3 Data analysis

Data from the focus group discussions were captured using historical trend analysis, preference ranking and a cropping calendar. Socio-economic factors and quantitative information on patterns of household use of the wetlands from the formal survey were examined using descriptive statistical analysis. MONQI generated economic indicators ranging from gross margin to net cash flow between farm-compartments and farm gate prices. Information obtained allowed estimation of the financial contribution of wetlands to farmers' livelihood and computation of gross margin (GM) and net cash flow (NCF) for crop production per household. The gross margin is defined as gross income minus the variable or direct costs. The NCF is an indicator for the cash generating capacity of a certain activity and is defined as the cash receipts minus the cash expenses.

The t-test was used to test the significant differences of GM and NCF between wetlands and hillsides. Household income ($ U.S.) indicators from different wealth classes and cropping activities in Cyabayaga and Rugeramigozi wetlands were analysed following analysis of variance (ANOVA) and their means were compared based on the LSD multiple comparison test at the 0.05 probability level. Correlation analysis was carried out for (i) field size and GM and (ii) field size and NCF. The statistical package used was SPSS 17.0 for Windows software.

4.3 Results and discussion

4.3.1 Household characteristics

A Rwandan household is principally defined as a nucleus family consisting of father, mother and children. In some households' relatives, mainly orphans who lost their parents during the 1994 Rwanda genocide, are adopted into the nuclear family. The household size in both research sites consisted of an average 6 persons. Table 4.1 summarize the characteristics of survey respondents and their households.

Table 4.1. Characteristics of survey respondents in Rugeramigozi and Cyabayaga watersheds, Rwanda, 2007.

Households characteristics	Description	Location	
		Rugeramigozi (n=96)	**Cyabayaga (n=157)**
Head gender (%)	Men	70.0	80.8
	Women	30.0	19.2
Family size (n)		5.5	6.0
Education (%)	None	25.0	18.4
	Primary	61.4	72.2
	Secondary	13.6	7.7
	University	0.0	0.0
	others	0.0	1.7
Age group (%)	<18	4.7	0
	18-55	76.7	89.9
	>55	10.2	10.1
Marital status of the head of household (%)	Single	21.5	3.1
	Married	60.0	82.9
	Divorced	0.0	1.4
	Widow	18.5	12.6

The majority of the households in both catchments are headed by men (Table 4.1). The women who head households are mostly widows. The 1994 genocide may be the main reason that in Rugeramigozi some households are headed by children under 18 years. Table 4.1 shows that in both sites most of the respondents have either primary education or are illiterate. Educated households compared to non-educated households are expected to have good knowledge of their natural resources and hence are expected to more easily adopt new technologies for improved wetland management (Bidogeza et al., 2009) and to improve their livelihoods. The ages of most of the heads of households were between 18 and 55 years (Table 4.1). This age range can be considered to be the “young generation” which is actively involved in agriculture, with a longer planning horizon, more adopters (Bidogeza et al., 2009) and therefore greater ability to improve wetland agriculture and hence their livelihood.

Labour for both crop and animal production is provided mostly by members of the household. Only 6% (Rugeramigozi) and 30% (Cyabayaga) of the respondents use hired labour to supplement family labour, especially for cash crops such as rice in Cyabayaga. A high demand for labour is observed in September and in February. In these months both wetlands and hillsides are prepared for cultivation and sown. Both men and women are involved in crop production; however men are more often involved in high income generating activities like rice production in wetlands and cow keeping, while women are more involved in hillside cultivation which focuses on food security. This form of task division may result in difficulties in organising labour especially during the peak growing season. Furthermore, the respondents mentioned that conflicts may arise when production fails to meet the consumption requirement or when disagreements surface about sharing intra-household surplus.

The main source of income for the households in both Cyabayaga and Rugeramigozi is sale of crop and livestock products. Other sources of income for men include: crafts work, construction/masonary, bicycle repairs and selling their labour on other farms. Informal trade is an important source of income for some women. Household income is spent on school fees for children, medical services, and basic household needs such as salt, sugar, soap and clothing. Men are mostly responsible for marketing and financial management of income. According to Kagabo et al. (2010), in Cyabayaga men spend three times as much time on the sales of the rice harvest as women. Expenditure on leisure is higher for men in both sites. These different patterns of income use reflect cultural and economic aspects of power relations between men and women in Rwanda.

4.3.2 Wealth classes and its impact on farmer’s livelihoods

Cows are the most important indicator of wealth status in Rwanda and elsewhere in sub-Saharan Africa (Achard and Banoin, 2003). This is due to the multiple functions that cows have in the economy of smallholder farms e.g. cows are a major capital investment and contribute to food security through provision of milk and meat. Other indirect benefits of cows include synergies at mixed farms which lead to improved crop productivity such as provision of nutrients from manure (Murwira et al., 1995). Other wealth criteria considered in the PRA were: farm size, hire or sale of labour, farm assets, off-farm income, and production orientation. Using the indicators of wealth status, farmers generated three different resource groups (RGs) (Table 4.2). Wealth indicators selected by farmers were almost the same across the two sites except the “farm asset” indicator which was only selected in Cyabayaga. Although the same indicators were chosen, class boundaries were chosen differently. For example a moderate wealthy farmer in Rugeramigozi has a farm size of 0.25-0.5 whereas a farmer with this size would be classified as poor in Cyabayaga.

The wide variability observed in resource endowment, indicates great variation between farms with respect to access to resources and production constraints. The poor group faces multiple constraints, which include small farm size, competing demands for labour, lack of manure and lack of cash to buy fertilizers. The largest proportion of the farmers belonged to resource group (RG) 2 with 50% and 70% in Cyabayaga and Rugeramigozi respectively.

Table 4.2. Indicators of the wealth status of the farmers and the characteristics of the different groups at Rugeramigozi and Cyabayaga, Rwanda.

Indicators	Rugeramigozi			Cyabayaga		
	RG 1 (rich)	**RG 2 (moderate)**	**RG 3 (poor)**	**RG 1 (rich)**	**RG 2 (moderate)**	**RG 3 (poor)**
Cow ownership	≥1	Share livestock keeping	No cow	≥1 breed	≥1 local	No cow
Farm size (ha)	>0.5	0.25-0.5	<0.25 and infertile	>1.5 ha	1-1.5 ha	<1.2 ha
Hire or sell of labour	Rarely hire	Sell for cash income	Exchanges labour, food	Hire	Rarely hire	No hire, no sell
Asset	-	-	-	Have at least a bicycle	Can have a bicycle	Poor housing
Off farm income	Most of the time	Focus on farm activities	On-farm labour	Yes	No	No
Production orientation	Surplus for market e.g. wine banana and maize	Banana, grain for subsistence	Food insecure, some begs to get food	Grain, vegetables for sale	Grain for Subsistence; sell vegetables, rice	Grain for Subsistence; sell rice

RG: Resource group

According to the FAO (1990), large resource availability is a key factor in determining the potential to acquire more farm resources for crop and livestock production by enabling transformation of outputs into inputs for additional enterprises in the agricultural system. It was found that rich resource households in Cyabayaga are able to hire labour for their farming enterprises. As a result rich resource households accomplish cropping and livestock tasks on time. Furthermore, households in RG1 and RG2 in Cyabayaga and Rugeramigozi have cows and hence access to free manure. By contrast the households in both study sites who were in the poor resource group (RG3) do not have cattle, and therefore lack manure to apply to their crops which limits their output productivity.

4.3.3 Land ownership, field sizes and spatial distribution

Table 4.3 shows information on land ownership, field sizes and their spatial distribution in Cyabayaga and Rugeramigozi. In Cyabayaga, most of the fields in hillside areas were obtained as a result of distribution by the government. Few farmers have bought additional land and some farmers came from outside the region and bought land for settlement (Table 4.3). In Rugeramigozi most of the farmers (74.9%) own fields through inheritance. In Cyabayaga 5% of the respondents mentioned that they do not own fields in wetlands, but keep livestock as their primary activity.

In Rwanda, farmers are partial owners of wetlands because all wetlands belong to the local government. This situation may have a negative impact on land management because farmers do not invest much in their fields because they are not full owners. In both Cyabayaga and Rugeramigozi, wetland fields were given to all individual farmers after reclamation regardless of their capacities. When one farmer is not interested or able to use his wetland field, another farmer is allowed to cultivate it through purchase or rental. Furthermore, the multi-resource characteristics of wetlands influence the structure of resource-tenure and management regimes. The huge demand on wetlands for a multitude of uses and functions often results in conflict between different users (Adger and Luttrell, 2000).

The average field sizes both in wetlands and on hillsides are larger in Cyabayaga than in Rugeramigozi. The surveyed households on average had about 0.3 ha in Rugeramigozi compared to 1.4 ha in Cyabayaga. Many households in Rugeramigozi cannot feed their families from their land only, either because field size is limited or production is not sufficient, or both. In Rwanda, field size is an important wealth indicator as discussed in section 3.2. According to Pottier (2006), the percentage of households below the poverty line was estimated at 67.9% for 2000 in Rwanda. Insufficient access to land was the most critical factor (Pottier, 2006; Nabahungu et al., 2011a). According to Mosley (2004), the size limit set by the FAO for a nutritionally viable household farm is at least 0.9 ha. In our case study only Cyabayaga meets this criteria.

The average number of fields per household was 5 in Rugeramigozi and 4 in Cyabayaga, the fields had an average size of 0.06 ha in Rugeramigozi and 0.35 ha in Cyabayaga. The fields were scattered at various distances from the house. Land policy (GoR, 2004) and land law (GoR, 2005) consider fragmentation of fields to be a problem with respect to improvement of agricultural production and consolidation of fragmented land is regarded by government (GoR, 2005) as a technique that will optimize production in the sector. However, Blarel et al. (1992) noted that consolidation policies are unlikely to increase land productivity significantly. Indeed, according to Musahara (2006), field fragmentation is a coping mechanism in smallholder agriculture in Rwanda, with each field having its own specific characteristics of fertility, accessibility and form of tenancy. This practice allows production of a wide range of crops in a variety of environments and protects against the risks of catastrophic crop failures caused by climatic extremes or pests (Conelly and Chaiken, 2000). In fact it has been shown that fragmentation is not always related to land scarcity (Musahara, 2006). For Rwanda, Blarel et al. (1992) favour field fragmentation, which, they argue, takes advantage of complementarities between crops, variations in soil types and differences in micro-climate.

Table 4.3. Field size, number and tenure in the wetland and hillside in Cyabayaga and Rugeramigozi watersheds.

Land characteristics	**Description**	**Location**	
		Rugeramigozi (n=96)	**Cyabayaga (n=157)**
Land size in hillside	Average (ha)	0.22[0.18]	0.87[0.88]
Land size in wetland	Average (ha)	0.09[0.06]	0.53[0.40]
Nr. fields	Average number	5.5 [1.5]	6.0 [2.3]
Ownership (%)	Wetland	95	89
	Hillside	100	100
Tenure in Hillside (%)	Inherited	74.9	10.7
	Given by state	5.0	61.4
	Bought	15.2	21.6
	Borrowed	4.9	6.3
Tenure in wetland (%)	Inherited	0.0	8.2
	Given by state	95.5	73.8
	Bought	15.0	35.7
	Borrowed	10.0	6.7

4.3.4 Cropping system in Cyabayaga and Rugeramigozi

Results from the PRA show that, the wetland farming system is different from the hill slope system mostly because of the nature of the wetlands environment and agriculture policy intervention. Rain-fed agriculture is practiced on hillsides whereas, in the wetlands, farmers practice both irrigation and rain-fed agriculture. Hillside agriculture in the research areas is characterised by a mixed farming system with a large diversity of crops e.g. beans, maize, banana, sweet potatoes, sorghum, cassava. Bananas and maize are the main crop in the hill slope plots in Rugeramigozi and Cyabayaga respectively. Bananas are often grown around homesteads and maintained over seasons. Potatoes, maize, beans, and sweet potatoes are intercropped under the banana plots in Rugeramigozi. This 'banana based' agricultural system extends from north-western Tanzania (Baijukya et al., 2005) to south-western Uganda (Briggs and Twomlow, 2002).

Although discouraged by agricultural officials who recommend pure stands, Rwandan households have developed complex farming systems based on a diversity of crops. Intercropping has a number of benefits including the spreading of risk from climatic extremes and pests, and the potential for a flexible mix of subsistence and commercial production (Conelly and Chaiken, 2000). Such systems also allow households to synchronize household labour requirements, access food for household consumption, and generate income with sales throughout the year. Furthermore, intercropping can reduce soil erosion which is a major problem in Rwanda(Huggins, 2009). Though the high crop diversity in Rugeramigozi and Cyabayaga may indicate land scarcity, as has been proven by many other studies of intensive agriculture in Africa (Stone et al., 1990; Lambert, 1996; Conelly and Chaiken, 2000), switching to monocropping as stated in the agricultural policy (GoR, 2005) may expose farmers to greater risk.

The land scarcity on hillsides has led to the need for wetland cultivation to improve farmers' livelihood. This is why the wetlands in Cyabayaga and Rugeramigozi are officially reclaimed for agricultural purposes. In order to manage the wetland and use it in an efficient uniform manner farmers are grouped into cooperatives and consolidate agricultural production by planting the same approved crop (Nabahungu and Visser, 2011a). Farmers have to agree on the planting regime, weeding and harvesting schedule, and application of agricultural inputs such as inorganic fertilizers and pesticides. This type of specialization is possible because wetlands are under state control. Farmers can cultivate in reclaimed wetlands under the condition that they implement the agriculture policy. In wetlands, rice monocropping is a common practice whereas maize and sorghum are cropped in rotation with legumes. Few farmers in both wetlands were cultivating vegetables, and only in the dry season. Rice is more extensively cultivated in Cyabayaga compared to Rugeramigozi. By continuous rice cultivation farmers are exploiting the same nutrients at the same soil depth. This may have the potential to reduce rice yields in the long term due to poor access of crop nutrients at deeper root zones.

4.3.5 Soil moisture and water management in the wetlands

The length of the moist period of wetland soils extend two to six months after the rainy season has ended, which provides an opportunity for dry season crop cultivation. However, there are indications that some places within the wetlands do dry shortly after the rains. Such variations in moisture conditions may be attributed to spatial variation in soil characteristics and conditions (such as soil depth, texture, organic matter content), which influence moisture retention capacity of the soil and can cause failure in wetland reclamation. In Rugeramigozi 76% of respondents cultivate in the wetlands in wet seasons, 24% of respondents noted that they do not cultivate in season B due to flooding since their fields are downstream. About 35% cultivate in the wetlands throughout the year. In Cyabayaga 12.5% of the respondents cultivate the wetlands throughout the year but the majority (82.5%) cultivates the wetland in the rainy season. This is related to the fact that most farmers in Cyabayaga cultivate rice which has a higher demand for water and labour.

In Cyabayaga 90% and Rugeramigozi 60% of the respondents reported that the wetland water levels are currently lower than in the past. The farmers indicated that the central part of wetland suffers the most. The main reasons given for these changes are inappropriate reclamation according to 60% of the respondents from Rugeramigozi and climate change (particularly inadequate rain and prolonged dry seasons between rains) according to 62.5% of the respondents from Cyabayaga. In both Cyabayaga and Rugeramigozi farmers also reported that the wetlands experience floods in some years. In Cyabayaga 65% and Rugeramigozi 77% of the respondents declared that the floods occur in season B while others have reported that the flooding occurs in season A. However, all agreed that flooding does not occur every year and is not severe.

Two main issues regarding wetland water and moisture management were highlighted during the PRA. First, the essential maintenance of common resources, such as the central drainage and irrigation channel, became a cause of conflict among farmers. The neglect of drainage and irrigation channels and to some extent the secondary channels, in wetland systems inevitably have an impact on adjacent wetland plots in terms of flooding or water reduction. To address such issues and solve conflicts, wetland cooperatives have been formed. The ability of these cooperatives to maintain equitable shared users and ensure sustainable wetland production is limited due to poor management of the cooperative committee. According to Nabahungu and Visser (2011a), farmers had little or no influence on the policies of their organizations. Although farmer led cooperatives can provide numerous benefits to members (Ortmann and King, 2007), according to Akwabi-Ameyaw (1997) these cooperatives have often not been successful in Africa because of problems in holding the management accountable to the members, and financial irregularities in management.

Secondly, there is no flexibility regarding crop rotation and rice monocropping to improve water use. Rice is the preferred and policy recommended cash crop (Nabahungu and Visser, 2011a) in wetlands even though it has a higher water demand than other crops. And one of the most often heard complaints in the two wetlands was the shortage of water which is reducing the yield. This situation is to some extend linked to poor wetland reclamation, the limited capacity of farmers to adapt to and cope with the changing micro-environmental conditions in the wetlands and also to the inflexible policy of a rice monoculture. Crop rotation which uses less water than rice monocropping can ensure both the maintenance of some hydrological functions as well as sustained production throughout the year.

4.3.6 Agriculture-livestock integration

Strong parallels exist between agriculture-livestock integration to improve farmer's livelihood and soil fertility management. It has been shown for Rwanda that the livestock density increases with the fraction of land used for crop production (Crawford et al., 2008). This is typical for agriculture that is limited by lack of nutrients: livestock primary serves as transport of nutrients from the pasture to the farm. With increasing occupation of the land for crops, the more than proportional increase of livestock and the zero-grazing policy, livestock progressively loses its nutrient replenishment function, while the land is depleted and degraded (Breman et al., 2007). Crop-livestock integration can play a role in soil fertility replenishment if grazing outside the farm is possible and/or if inorganic fertilizers are used on a reasonable area of land.

Farmers identified two systems that are used in livestock production in Cyabayaga and Rugeramigozi; a semi-intensive system where animals are kept at home and fed through cut and carry (zero-grazing) and a semi-extensive system in which animals graze in natural pasture. Due to national agricultural policy restriction on free grazing most farmers are obliged to practice zero-grazing. The semi-extensive system is still found in Cyabayaga but represents less than 5% of the population having large herds. Most farmers in Cyabayaga now focus on agriculture integrated with a limited number of livestock. It was reported by the village leaders that the government instructed farmers to allocate areas for livestock keepers (paddocking) as a way to integrate both land use systems and to minimise conflicts. Planting of fodder species, use of crop residues and zero-grazing are progressively practiced by all farmers in Cyabayaga. Musahara and Gasarasi (2005) stated that although the idea of fenced grazing land might be a step toward more professional cow keeping, there are indications that the poor cattle keepers will lose their right to the traditional common property. The same study noted that disputes over pastures were more frequent among poor cattle keepers than among the wealthier (Musahara and Gasarasi, 2005).

Cross-bred or improved cattle breeds are kept in sheds close to the homestead in both sites. This could be in response to the Government policy of 'one-family-one-cow' being implemented in the country. This program aims at enabling every poor household to own and manage an improved dairy cow which would help the family to improve their livelihood through increased milk and meat production and to improve soil fertility of their land for their crops using the available manure.

Households in Cyabayaga had more cows than in Rugeramigozi, where the farmers are more likely to rear goats and pigs than cows (Musahara, 2006). This is understandable given the higher land scarcity in Rugeramigozi. Fodder for the stalled animals, both in Cyabayaga and Rugeramigozi, is obtained either from grass cut and carried from the wetlands and dry land areas or from crop stubble after harvesting. Napier grass and weeds, sourced from around the farm plots, are also used to feed livestock. Napier grass was mainly grown along field boundaries for crop plots. Some farmers in Cyabayaga live near the rice factory and use rice bran and straw as fodder, especially during the harvest period.

In Rugeramigozi, few farmers own cows; they get supplementary fodder from the ridge in wetlands and also from the short fallow period after harvesting during the dry season in wetland. If the one family one cow policy would be applied in Rugeramigozi, fodder availability will become a limiting factor.

In Cyabayaga cows are normally watered in the valley wetlands and along the surrounding rivers/streams. Concerning the grazing conditions in the wetlands, it was reported that it was easier to graze livestock in the wetlands in the past. Most of the changes are reported to have taken place around year 2003. One of the major constraints faced by livestock keepers is the fact that the wetlands suitable for grazing are those areas that are reclaimed for rice cultivation.

4.3.7 Contribution of wetlands to food security and income: MONQI Results

Farmers cultivate the wetlands for two main reasons 1) to sell harvest for income generation and 2) to satisfy household food requirements. Crop production yields an estimated annual GM per household of $ 2582 and NCF of $ 2113 in Cyabayaga (Table 4.4). In Rugeramigozi, the annual GM is of $ 359 and NCF of $ 176. However, there is large variation among households in both sites, indicated by a high standard deviation. The variation may be due to different household resource groups. Between the sites, statistically significant differences ($P<0.01$) are observed between season A and B. At both sites, more than 90% of both GM and NCF are generated during the wet seasons. Considering that agriculture is the main source of income, results from Table 4.4 suggests that farmers in Rugeramigozi are less wealthy compared to Cyabayaga.

Table 4.4. Household income (in $) generated from wetland and hillside cultivation for different seasons in Cyabayaga and Rugeramigozi catchment, Rwanda.

		GM			**NCF**		
	Seasons	**Wetland**	**Hillside**	**T test**	**Wetland**	**Hillside**	**T test**
Cyabayaga	A	864[675]	384[314]	3.3**	819[682]	261[282]	3.9***
	B	872[631]	297[146]	4.6***	743[609]	170[103]	4.9***
	C	165[74]			120[72]		
Subtotal		**1901**	**681**		**1682**	**431**	
Rugeramigozi	A	24[22]	111[131]	-3.4**	5[9]	69[105]	-3.1**
	B	34[42]	164[184]	-3.6**	14[16]	75[122]	-2.6*
	C	26[19]			13[6]		
Subtotal		**84**	**275**		**32**	**144**	

Numbers in bracket represent standard deviation; *significant at 0.05, **significant at 0.01, ***significant at 0.001

Comparison of incomes generated from the wetlands with hillside income sources illustrated considerable differences between the two cases studies in terms of absolute incomes and the proportion generated through wetland agriculture (Table 4.4). In Cyabayaga, the overall contribution of wetland cultivation was 74% to GM and 80% to NCF per household per year. In Rugeramigozi, the overall contribution of wetland cultivation was 24% to GM and 18% to NCF per household per year. These results are similar to other studies which have found a wide range in household income generated from wetlands cultivation in Africa (Emerton et al., 1999; Adekola et al., 2008; Rebelo et al., 2009). Overall, wetland GM is estimated to range from $6 to $2761 per household per year (de Groot et al., 2002). Furthermore, in general gross margin in both sites were statistically different within wealth classes (Table 4.5). Only in Rugeramigozi was the gross margin from the wetland cultivation of the rich households not statistically different from that of moderate households. This observation may be due to the fact that the land size of the moderate and rich farmers in the Rugeramigozi wetland is the same. The differences between the case studies, in relation to both absolute income and the relative contribution from the wetlands can be explained by the variation in farm size and wealth classes. Both GM (Figure 4.1) and NCF (Figure 4.2) were statistically (P<0.001) correlated with land size. For Cyabayaga, the relatively large and newly cultivated fields ensure high crop production. The relatively low contribution of the wetland to income in Rugeramigozi, results from the fact that the average field size in the wetland is very small (Table 4.3). Although in Rugeramigozi the relatively high rainfall provides opportunities for crop diversification, land shortage and the low fertility of the fields (Nabahungu and Visser, 2011a) lead to low production.

Table 4.5. Gross margin ($year^{-1}$) between wetland and hillside plots among different resource group farm.

Niches	Resource groups	Rugeramigozi		Cyabayaga	
		Gross margin *(US$ $farms^{-1}$)*	Gross margin *(US$ ha^{-1})*	Gross margin *(US$ $farms^{-1}$)*	Gross margin *(US$ ha^{-1})*
Hillside	Rich	635.6 (157.0)[a]	1080.8(203.0)[a]	934.7 (370.5)[a]	508.3 (248.0)[a]
	Moderate	158.2 (8.0)[b]	833.4 (198.7)[b]	576.1(47.0)[b]	451.7 (61.1)[ab]
	Poor	44.6 (26.0)[c]	362.6 (123.7)[c]	306.8(140.5)[c]	319.6 (117.9)[b]
Wetland	Rich	104.0 (42.4)[a]	900.7 (467.3)[a]	3414.3 (1555.1)[a]	3314.8(435.0)[a]
	Moderate	89.15 (49.6)[a]	629.9 (145.3)[a]	1903.2(99.3)[b]	3499.5(488.2)[a]
	Poor	38.6 (23.7)[b]	541.5 (174.4)[b]	666.1(374.7)[c]	2153.4(937.5)[b]
T test		**3.8*****	**0.8[ns]**	**-4.27*****	**-12.91*****

Different letters in superscripts within rows of the same niche refer to significant differences (P<0.05) according to LSD multiple separation test; Numbers in bracket represent standard deviation; ***significant at 0.001 and ns=non-significant

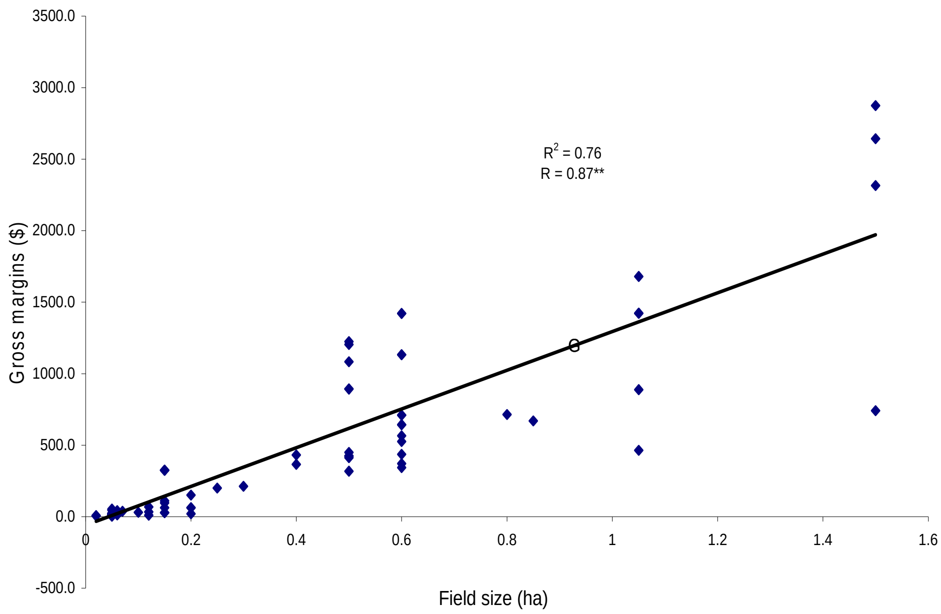


Figure 4.1. Correlation between field size and household gross margin per cropping season in Cyabayaga and Rugeramigozi wetlands.

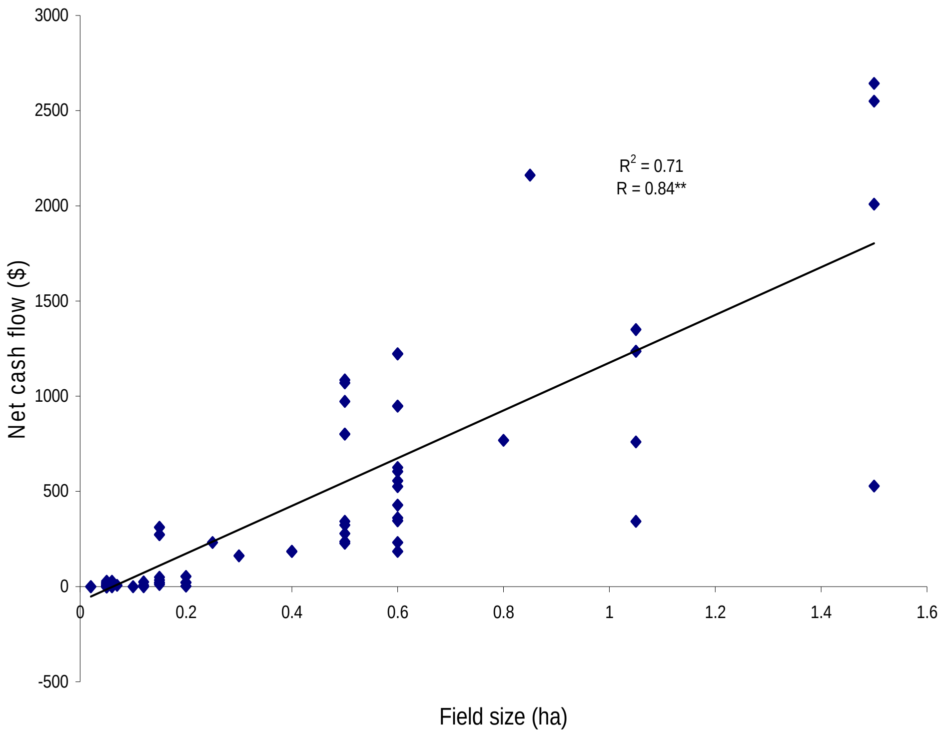


Figure 4.2. Correlation between field size and household net cash flow per cropping season in Cyabayaga and Rugeramigozi wetlands.

In Cyabayaga 68% of farmers were using diamonium phosphate (DAP) and urea at the rate of 100 kg ha^{-1} each on rice whereas in Rugeramigozi only 10% of farmers used urea at a rate of 50 kg ha^{-1}. The use of inorganic fertilizer in Cyabayaga can be related to the relatively large size of fields which leads to a high return on cropping activities and thus a higher income level. These results are consistent with the conclusions of Kagabo et al. (2010). They assert that high income from rice in Cyabayaga wetland was due to a relatively good yield, good prices obtained for paddy rice and the use of inorganic fertilizer. According to Adesina (1996), one of the main factors that influence farmers' use of fertilizer in Côte d'Ivoire is farm size. It has been reported that larger farms are more likely to adopt innovations compared to small farms due to either economies of scale or preferential access to inputs and credit (Polson and Spencer, 1991). Furthermore, according to Nabahungu and Visser (2011a, ch 3), soils in the Rugeramigozi wetland had a low fertility compared to the soils in the Cyabayaga wetland.

Table 4.6. Household income ($ U.S) from different cropping activities in Cyabayaga and Rugeramigozi wetlands, Rwanda.

Sites	Crops	GM	GM ha^{-1}	NCF
Rugeramigozi	Rice	34 [16]	684 [322]	9 [10]
	Bean	20 [14]	299 [167]	5 [8]
	Sorghum	35 [38]	356 [168]	14 [15]
	Tomato	58 [6]	1099 [112]	45 [7]
	Cabbage	41 [16]	622 [43]	28 [8]
F test		**2.4^{ns}**	**21.8*** **	**12.8*** **
Cyabayaga	Rice	1045 [688]	1658[536]	954 [690]
	Bean	412 [166]	599[106]	292 [128]
	Maize	513 [226]	849[31]	440 [231]
	Tomato	1392 [1165]	2135[610]	1278 [1101]
F test		**2.5***	**16.1*** **	**3.54***

Numbers in bracket represent standard deviation; ns: not significant, *significant at 0.05, ***significant at 0.001

The analysis of variance (ANOVA) shows statistical differences between the returns of cropping activities in the two wetlands except for the GM in Rugeramigozi (P>0.05) (Table 4.6). For the same cropping activities, the GMs computed per ha are higher in Cyabayaga than in Rugeramigozi. This observation confirms the lower soil fertility status and lower use of fertilizer in Rugeramigozi compared to Cyabayaga. The results of multiple comparison of rice with other cropping activities are presented in Table 4.7. Rice and tomato activities contributed highly to household income at both sites. Although tomato showed a high potential for income generation, it was cultivated by only a few farmers in the dry season in both wetlands (12.5% in Rugeramigozi and 9.6% in Cyabayaga). According to the PRA, a limited number of farmers cultivate tomatoes due to the prevalence of diseases on tomato in the rainy season, and difficulties with storage of tomatoes which leads to low prices at harvesting time. In Cyabayaga, the results clearly show the importance of rice farming to household income, which is on average of $1045 U.S. per season. Also Kagabo et al. (2010) found that the gross return per season from rice production in Cyabayaga varies between $ 1129 U.S. on plots irrigated on a weekly basis and $ 979 U.S. on plots with a fortnightly irrigation schedule. Since the Cyabayaga wetland has been under irrigation for the last 30 years, farmers are now familiar with rice cultivation although they still face difficulties in water management. Wetland development improves rice production but also implies the increasing displacement of lowland crops, thus reducing crop and livelihood diversification. According to Nabahungu and Visser (2011a, ch 3), continuous cultivation of rice in the Cyabayaga wetland has led to problems with various pests and diseases. Although beans are a staple crop in Rwanda they have never been produced as source of income. An effort to introduce high yielding bean varieties, which can be used as rotation crop with rice, could increase agricultural sustainability and improve both food security and cash income from wetlands.

Table 4.7. Multiple comparisons (LSD) between income ($) from rice and other different cropping activities in Cyabayaga and Rugeramigozi wetlands, Rwanda

			LSD means differences (i-j)		
	Reference crop	**Crops in comparison**	**GM**	**GM ha^{-1}**	**NCF**
Rugeramigozi	Rice	Beans		385***	4.52^{ns}
		Sorghum		328***	-4.9^{ns}
		Tomato		-415**	-35.6***
		Cabbage		62ns	-18*
Cyabayaga	Rice	Beans	633*	1059***	662*
		Maize	531*	810***	514*
		Tomato	-347*	-476^{ns}	-323^{ns}

ns: not significant, *significant at 0.05, **significant at 0.01, ***significant at 0.001

4.4. Conclusions

Wetlands play a crucial role in the provision of household food security and income in Rwanda. The intensity, pattern of utilisation of wetlands and contribution to livelihoods depend on the type and setting of wetlands in the catchment. A strong linkage between farming in wetlands and on hillsides is required to support the livelihood of farmers. Therefore, hillside and wetland management need to be integrated in Rwanda. Increased attention to integration of agriculture and livestock when designing new technologies is required, with attention to the benefits of reliable long term production, contribution to fodder supply and soil fertility improvement in addition to direct, short term yield of a particular crop. The results show that most people in the study areas in Rugeramigozi and Cyabayaga use wetlands to grow rice, maize, beans, vegetables and sorghum. In both case studies, the wetlands made an appreciable contribution to household income through their use for agricultural production. The scarcity of wetland fields and poor soil fertility in Rugeramigozi results in a lower contribution to farmers' livelihood compared to the situation in Cyabayaga. Much heterogeneity in crop generating income is observed within and between the sites. Household dependence and demands on wetlands, and both the absolute and proportion of household income generated from wetlands are significantly affected by site and farmer resource group. Hence incentives for management of wetland resources need to differ markedly from one location to another and include consideration of the categories of farmers' resource endowment.

The case studies show that the greatest threats to wetlands and causes of reduced wetland productivity are associated with water scarcity, monocropping and weak farmer organizations. The complexity identified within this study, emphasizes the need for a critical analysis of the biophysical, social and economic factors that underpin the dynamics of wetland resource use prior to their large scale reclamation. In order to harness this opportunity there is need for sustainable management of these wetlands.

This research is useful for policy and decision making regarding alternative management and use options of wetlands in Rwanda and in other similar areas of the world. For example the data shows that vegetable production in the dry season, which is at present practiced by only a few farmers, may be an option for improving livelihoods in the Rugeramigozi wetland. Productivity enhancing technologies e.g. improved crop rotation using high yielding legumes can be introduced and adopted by farmers as a way of increasing and sustaining productivity. Furthermore, a delicate balance must be struck between using the rich wetlands resources now for agriculture and their conservation for the future. This is essential as the future will not exist if the present is overexploited.

This research has shown that different developmental interventions for sustainable wetland management, both in policy and in technology, are needed in order to increase the income and ensure the future livelihoods of farmers with no, or limited, land and who are dependent on wetland resources.

Chapter 5

Nutrient resource flows in agricultural wetland and hillside fields in Rwanda, as affected by farmers' resource endowments

This paper is under review as:

Nabahungu, N.L., van Beek, C.L., Visser, S.M., Mowo, J.G. and Vanlauwe, B., 2011. Nutrient resource flows in agricultural wetland and hillside fields in Rwanda, as affected by farmer's resource endowments. Agriculture, ecosystems and environment.

Nutrient resource flows in agricultural wetland and hillside fields in Rwanda affected by farmers' resource endowment

Abstract

The aim of this study was to analyse resource use strategies and its potential impacts on the fertility of wetland and hillside soils, as affected by farmers' resource endowment. Information on resource flow and use strategies was collected within farming households managing wetland and hillside fields in the Cyabayaga and Rugeramigozi catchments of Rwanda. The two wetlands were selected to represent reclaimed wetland agriculture in Rwanda because they provide contrasts in both environmental and social terms. Three tools were used: 1) focus group discussion, 2) soil sampling for chemical analysis and 3) Monitoring for Quality Improvement (MonQI). Differences between hillside and wetland, and farmer groups based on resource availability were observed for input use (e.g. 9.4 to 169.0 N kg ha^{-1}), output (e.g. 24 to 134.5 N kg ha^{-1}), partial nutrient balances (e.g.-4.8 to 34.5 N kg ha^{-1}) and general soil fertility status, despite strong differences across sites. Nutrient input, output and partial balances are higher in Cyabayaga compared to Rugeramigozi except for P. Results show that agricultural potential, farming system (choice of crops),access to resources, gross margin, size of livestock herd and farmers resource endowment influence the magnitude and the degree to which nutrients fluxes may be imbalanced. Rice cultivation can explain high rates of inorganic fertilizer application in Cyabayaga wetland. This study highlights the assertion that farmers may not necessarily be concentrating nutrients around their homestead because of the short distance. Rather, farmers apply nutrients in plots which they perceive to be fertile and secure to produce satisfactory yields. Thus, the amount of resources used at the farm level is closely tied to the potential increase in productivity to be gained. The value and marketability of the crops produced are therefore critical factors in the decision to invest in soil fertility improvement.Furthermore, the case study highlights the importance of linking hillsides and wetlands in analysing farm household systems in Rwanda.

5.1 Introduction

Agricultural development of wetlands in Sub-Saharan Africa has been stimulated by demographic change, commercialization, technological change and government policies (Dixon and Wood, 2003). For example, the green revolution and associated intensive input resulted into massive rice production in many wetlands in South-East Asia. In Southern and Eastern Africa, many policies and programmes favour exploitation of wetlands for economic development (Dixon and Wood, 2003). Experiences in wetland programs in Ethiopia, Uganda, Rwanda and South Africa, and irrigation policies in Malawi and Zambia show increased interests in wetland agriculture (Dixon and Wood, 2003; Nabahungu and Visser, 2011a ch3). In Rwanda by 2008, about 148000 hectares out of the total of 278000 hectares of wetlands in Rwanda were already under cultivation (REMA, 2009).

Population density in Rwanda has risen rapidly over the last 4 decades and is now with averages varying from 350 till 600 people km^{-2} the highest in Africa (Bidogeza et al., 2009). Agriculture is the backbone of the economy and contributes about 41% to the GDP and more than 72% to all exports (REMA, 2009). Rwanda's farmers have responded to the pressure on the land and the associated decline in productivity by expanding their agricultural activities into the fragile wetlands and to the steep slopes. The cultivation of marginal lands and the large scale reclamation of the wetlands have led to the degradation of these resources, with the risk of losing the productive capacity of the land. Stoorvogel and Smaling (1990) revealed that Rwanda has one of the most severe declining nutrient rates in Africa, with on average -54 kg N, -9 kg P and -47 kg K ha^{-1} $year^{-1}$. Without investment in land improvement, soil erosion and soil fertility decline will continue, leading to low agricultural productivity and hence increased food insecurity and reduced cash income.

The government of Rwanda (GoR) launched in 2008 a crop intensification program aiming at mobilizing farmers to adopt modern farming systems, including the use of improved varieties, fertilizers and pesticides (REMA, 2009). Currently, the use of inputs is still limited to few farmers in the Northern Province cultivating potatoes and for rice producers in Eastern Province and Bugarama wetland (Naramabuye et al., 2009). One of the main constraints to crop intensification in Rwanda is the commodity based approach practised although it is recognised that natural resource management (NRM) has to be tackled at the scale of the farming system, including the wetlands (Nabahungu and Visser, 2011a and b). Natural resource management considers not only technical factors, but also socio-economic aspects and the influence of the policy framework. Furthermore, there is social differentiation and spatial variation in resource availability among smallholder farms in Rwanda, meaning that technologies and practices that seem feasible and eligible in one location or for one social group may not necessarily be so in another location or other social group. According to Giller et al. (2006), some of the nutrient flows and transfers that result in gradients in soil fertility vary strongly among farmers of different social status; notably between cow owners and non-cow owners. Furthermore, nutrient management of different fields belonging to one single farm may vary considerably (Smaling et al., 1996). Farmers' decisions on soil fertility management are influenced by both the socio-economic and the biophysical environment, resource endowment and production objectives (Tittonell et al., 2005; Haileslassie et al., 2007).

Although, there is evidence of important heterogeneity and diversity in farming systems in Rwanda, detailed resource flow studies at the field and landscape scale are scarce. As a result, it is not well known how nutrient management practises are affected by or embedded in the livelihood strategies of rural households (e.g. crop selection, source of farm income, labour use and agricultural systems). Furthermore, it is uncertain how the location of a farmers' plot within the landscape affects nutrient management of that specific plot. Resource flows at the scale of a field and the landscape can provide information on how environmental and socio-economic conditions and agricultural management affect the variation in nutrient flows between and within the fields of a farm. Understanding farm resource use strategies in the wetlands require a comprehensive assessment of the system of cultivation in the hillsides and wetlands and their interrelationships within the wetland agricultural systems in Rwanda. The objective of this study was to analyse resource use strategies and their potential impact on soil fertility for wetland and hillside soils, as affected by farmers' resource endowment. Resource flows were measured for farmers belonging to various farmer resource groups and to two representative catchments in Southern and Eastern Rwanda.

5.2 Materials and Methods

5.2.1 Research area

The Cyabayaga and Rugeramigozi wetlands (Figure 3.1) were selected to represent typical wetland agriculture in Rwanda (MINAGRI, 2002). In Cyabayaga and Rugeramigozi wetlands, farmers are grouped in cooperatives and consolidate agricultural production by planting the same crop approved by the cooperative (Nabahungu and Visser, 2011a, ch 3), in order to manage the land and use it in an efficient uniform manner. Farmers have to agree with the planting regime, weeding and harvesting schedule, and with the applied agricultural inputs such as fertilizers and pesticides.

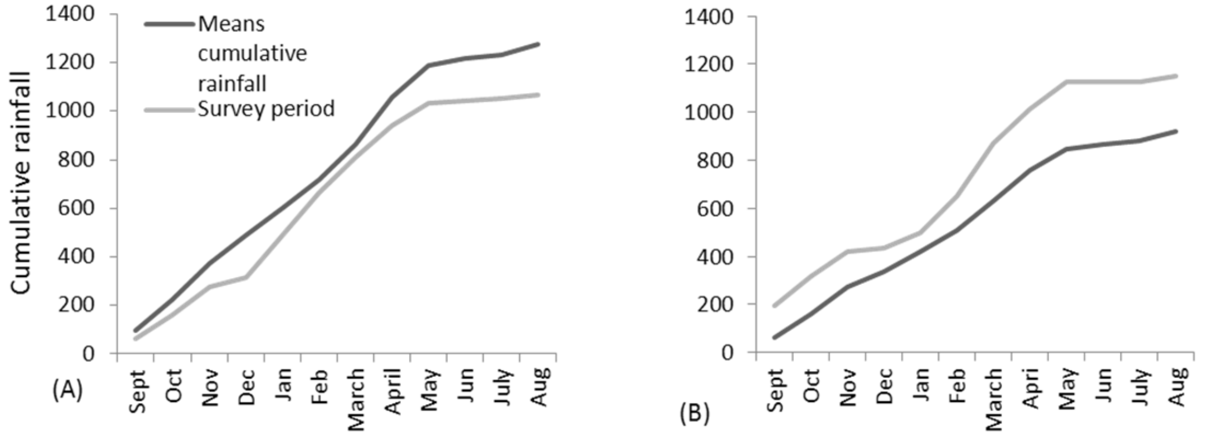


Figure 5.1. Cumulative mean rainfall during last ten years and for the surveyed period of season A and B in (A) Rugeramigozi, (B) Cyabayaga.

The Cyabayaga wetland is located in Nyagatare District (1°22' 51.6" S, 30° 17' 07" E), Eastern Province of Rwanda. It is part of the eastern savannah agro-ecological zone lying about 1400m a.s.l and has an area of 1080 ha. Before 1969 the Cyabayaga catchment was a hunting zone. In 1970 the hillsides were converted into settlement and cultivation areas. In 1978, the wetland was reclaimed for rice production. After 1994 genocide, there was a new settlement for returning exiles from neighbouring countries.

The Rugeramigozi wetland is located in Muhanga District (02° 07’ 40’’ S, 29° 45’ 20’’ E), Southern Province. It is located on the plateau agro-ecological zone of Rwanda at around 1650m a.s.l and covers an area of 225 ha. After official reclamation in 1999-2000, the land was redistributed by the Wetland Cooperative. Since the beginning of the 19th century until official reclamation, the wetland was cultivated only in the dry season (Season C) from June to September. Nowadays (2010) farmers do cultivate the wetland throughout the year.

The annual range of rainfall is 1200-1400 mm in Rugeramigozi and 800-1000 mm in Cyabayaga. The rainfall pattern in Rwanda is bimodal (Figure5.1) with the short, most important and reliable rainy season from September to January (named Season A). The long rains season runs from mid-February to May (Season B) and has high intensity rainfall.

At both sites, the surrounding catchments are characterized by gentle hillsides gradually converging into wetlands. The village set up in the hillsides consists of mainly scattered households. Farmers in the catchment have fields both on the hillsides and in the wetlands; however fields in the wetlands are located at large distances from the homestead compared to fields on the hillsides. In both Rugeramigozi and Cyabayaga farmers have experienced decline in productivity of their land due to over-cultivation and soil erosion from the hillslopes (Nabahungu and Visser, 2011a, ch 3).

The two case study sites represent two important aspects in wetland agriculture. First, Rugeramigozi lies in the highly populated central plateau zones of Rwanda where pressure on land is very high. Hillslope soils are infertile but rainfall is relatively high and reliable. Because of the high land pressure, and the relatively high fertility of the wetland soils, wetlands are absolutely important sources of livelihood. The Cyabayaga wetland is situated in the drought prone eastern savannah zones where the continuous availability of moisture in the wetland ensures better crop yields compared to the hillsides. Land pressure is relatively low and soil fertility is perceived to be better compared to Rugeramigozi.

5.2.2 Household selection and resource group identification

The PRA provided background information on the agricultural management, production system and farmer groups' stratification. Focus group discussions with selected farmers (elders and leaders) were conducted to provide qualitative and quantitative insights into use of fields in the wetland and on the hillside. The group comprised seven men and seven women in each site. A checklist was developed and pre-tested during the preparatory stages of the focus group discussion to guide the discussion. Participatory wealth ranking was implemented to delineate wealth classes and categorise household diversity. The methodology and farmers' criteria are detailed described in Nabahungu and Visser (2011b, ch 4). The income groups were generalized into three main resource groups: poor, moderate and rich for ease of categorization by key informants in the study sites (Table 5.1).

Table 5.1. Indicators of the wealth status of the farmers and the characteristics of the different groups.

Indicators	Rugeramigozi			Cyabayaga		
	RG 1 (Rich)	RG 2 (Moderate)	RG 3 (Poor)	RG 1 (Rich)	RG 2 (Moderate)	RG 3 (Poor)
Cow ownership	≥ 1	Share livestock keeping	No cow	≥1 breed	≥1 local	No cow
Farm size (ha)	>0.5	0.25-0.5	<0.25 and infertile	>1.5 ha	1-1.5 ha	<1.2 ha
Hire or sell of labour	Rarely hire	Sell for cash income	Exchanges labour, food	Hire	Rarely hire	No hire, no sell
Asset	-	-	-	Have at least a bicycle	Can have a bicycle	Poor housing
Off farm income	Most of the time	Focus on farm activities	On-farm labour	Yes	No	No
Production orientation	Surplus for market	Banana, grain for subsistence	Food insecure	Grain, vegetables for sale	Grain for Subsistence; sell vegetables, rice	Grain for Subsistence; sell rice

*Adapted from Nabahungu and Visser, 2011b, chap 4 of this thesis

5.2.3 Field identification, soil sampling and analysis

Soil samples were collected to obtain knowledge of the current level of soil fertility and also to provide background information about soil nutrients stock. From each wealth class, 3 farmers were selected to provide composite soil samples; one sample from the wetland plot and one from the hillside plots. A total of 36 samples were collected in both sites at 0-20 cm depth. All soil samples were air dried, passed through a 2-mm sieve and analysed. Soil pH was determined in 1:2.5 soil:water ratio, texture was measured by the hydrometer method (Bouyoucus, 1951), and soil organic carbon was determined by the wet oxidation method (Walkley and Black, 1934). Available P was determined using the method of Bray 1 (Bray and Kurtz, 1945), while total N was determined by Kjeldahl digestion, distillation and titration. Exchangeable K was analysed using an atomic absorption spectrophotometer following an ammonium acetate extraction. Cation Exchange Capacity (CEC) was determined at pH 7 using ammonium acetate as exchange cation.

5.2.4Nutrient and economic flows analysis

The criteria used during PRA to identify farmer resource groups were presented to the key informants prior to the interviews to obtain a list of 9 poor, 9 moderately poor and 9 rich households in each study site. Finally, 27 households for each study site were interviewed about their farm management practices using the MonQI standardized questionnaire (van Beek et al., 2009). Interviews were performed six times at the start and the end of each cropping season considering the bimodal rain season in Rwanda (seasons A and B)and the dry season in wetland (season C). Equivalence between measurement units used by local people and standard units were estimated through direct field observation and measurements.

To analyse the resource flow the Monitoring for Quality Improvement (MONQI) toolbox was used. MONQI is a methodology for monitoring management and performance of small scale farming systems world-wide (www.monqi.org). MONQI is dedicated to the monitoring of agricultural systems in the tropics with the aim to improve the quality of farm management, crop production, quality of production, living standards and environment. Detailed information on nutrient flows and financial indicators at activity level, niche (wetland versus hillside) level and farmer level were collected using the MONQI toolbox (van den Bosch et al., 1998).Partial nutrient budgets for each farm household were estimated by outflows in crop products (OUT1) and outflows in crop residues (OUT2); and inflows in inorganic (IN1) and organic fertilizers (IN2). Labour flow data between the farm plots within the system provided a comparative basis for analysing subsystems of the farm. A daily labour calendar was described by the farmers for typical working days. The number of working days per week was also described taking into account the days for social activities. The gross margin was calculated as gross income minus the variable or direct costs. The family labour was not taken into account for gross margin computation.

For resource flows per hectare, the hill slope plots were aggregated in a weighted average for the hillside plots to compare with the wetland plot of the same farmer. Whilst for labour input and gross margin flows per farm, the normal average of hillside plots were used to compare with wetland plots of the same farmer. Farmers in study sites often had one wetland plot.

5.2.5 Statistical Analysis

The statistical significance of the differences between sites, niches, and farmer resource groups and their interaction was assessed by analysis of variance (ANOVA) of mixed model, with Genstat 13.2 and their means were compared based on LSD at the 5 % critical level.

Regression analysis was done with STATA to generate the estimates of specified variables assumed to affect the variation of the nutrients flux. Given that the data are plot and household specific; the observations were clustered at household level.

5.3 Results

5.3.1 Soil Fertility status

According to the soil analysis on major nutrients, pH and organic carbon (Figure 5.2), soils of Rugeramigozi are have a low fertility compared to soils of Cyabayaga ($P<0.001$). Furthermore, contrary to Cyabayaga, the status of soil fertility in Rugeramigozi wetland is low compared to its surrounding hillsides ($P<0.01$). There was a significant interaction ($P<0.05$) exists between sites and niches for carbon and nitrogen content and between sites and resource farm group ($P<0.05$) for carbon, nitrogen and phosphorus while a significant interaction ($P<0.05$) between niches and farm resource groups for carbon content, nitrogen and potassium. Soil pH is strongly acidic in Rugeramigozi and slightly acidic in Cyabayaga. Except for soils in the wetland fields in Cyabayaga which have medium levels of organic carbon and total nitrogen, all fields have low total N and organic carbon content (Landon, 1991). Bray1 P is medium in all parts of the sites except in Rugeramigozi wetland where it is low according to rating of Landon (1991). According to Landon (1991), K is in medium range in Rugeramigozi and high in Cyabayaga. The low pH values are often combined with high concentrations of soluble aluminium and P fixation.

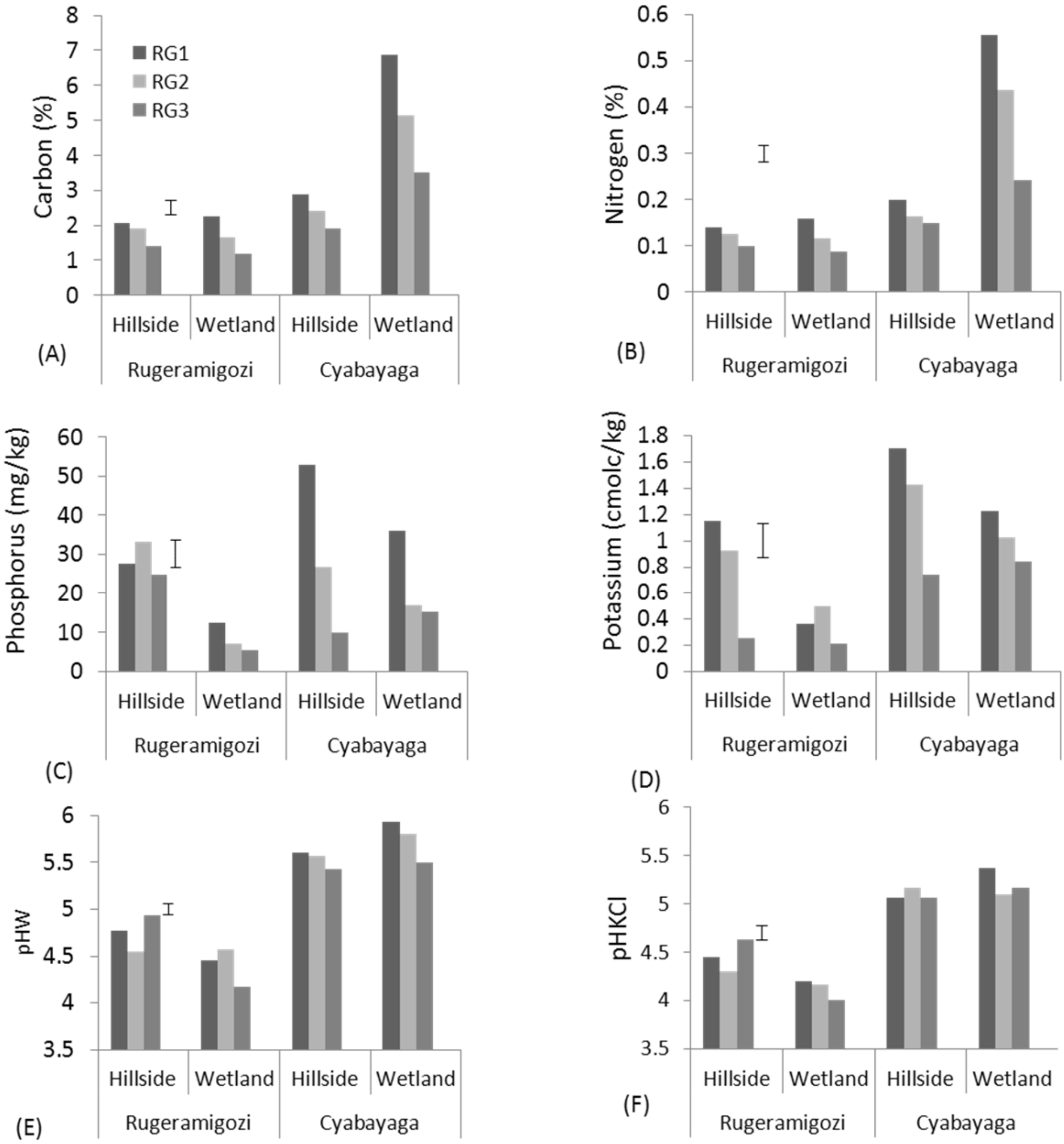


Figure 5.2. Characteristics of soils from field of rich (RG1), moderate (RG2) and poor (RG3) resource groups in Rugeramigozi and Cyabayaga. (A) Carbon content (%), (B) Nitrogen (%), (C) Phosphorus (mg kg-1), (D) potassium (cmolec kg^{-1}), (E) pH water and (F) pH KCl. Vertical bars represent the standard error of the differences (S.E.D).

5.3.2 Land, labour allocation and crops gross margins

The total field size per household in wetlands was small compared to hillsides in both sites ($P<0.001$) (Figure 5.3A). On average rich farm households owned more land than the medium households ($P<0.001$) (Figure 5.3C). However, separating Rugeramigozi from Cyabayaga showed that in Rugeramigozi wetland the land size is the same for both groups ($P<0.01$). Intermediate households owned more land than the poor households ($P<0.001$). The land size in Cyabayaga was bigger than in Rugeramigozi both in wetland and in hillsides ($P<0.01$) (Figure 5.3B).

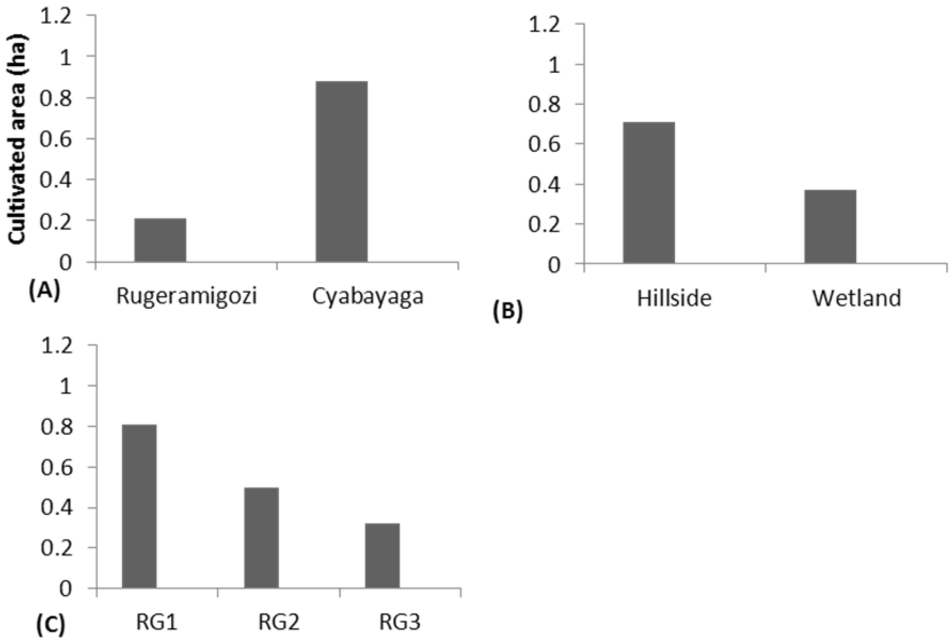


Figure 5.3. Area of cultivated fields in Rugeramigozi and Cyabayaga. (A) Average total area of cultivated fields in Rugeramigozi and Cyabayaga; (B) Average area of cultivated fields in wetland and hillside; (C) Total area of cultivated fields for rich (RG1), moderate (RG2) and poor (RG 3) resource groups. Farms were classified according to a typology (farm types 1-3). Vertical bars represent the standard error of the differences (S.E.D).

Rich households were able to allocate more labour to both wetland and hillside plots in Cyabayaga and Rugeramigozi (Figure 5.4A). According to the PRA, this significant increase in labour allocation was achieved by hiring labour from other households. Poor resource households were selling their labour to rich resource households. The total labour allocated in wetlands is low compared to labour allocated to hillsides (Figure5.4B). This significant difference ($P<0.01$) can be partly explained by the difference in land holding sizes between the two study niches (Figure 5.3B). However, generally crops cultivated in wetlands require a higher labour intensity. In Rugeramigozi total labour input to the farms is significantly ($P<0.001$) less than labour input in Cyabayaga (Figure 5.4A). This is related to farm size (Figure 5.3). Rice grown in the wetlands is also a major cash crop in Cyabayaga whereas hillside plots are mainly for food crop production. The PRA showed that, since rice is labour demanding, farmers in Cyabayaga invest more labour through hired labour to their wetland. Labour and capital investments are closely related; since labour may be purchased or may have to be sold, and since purchased agrochemicals such as mineral fertilizers can substitute for labour-demanding management such as composting and applying organic manure.

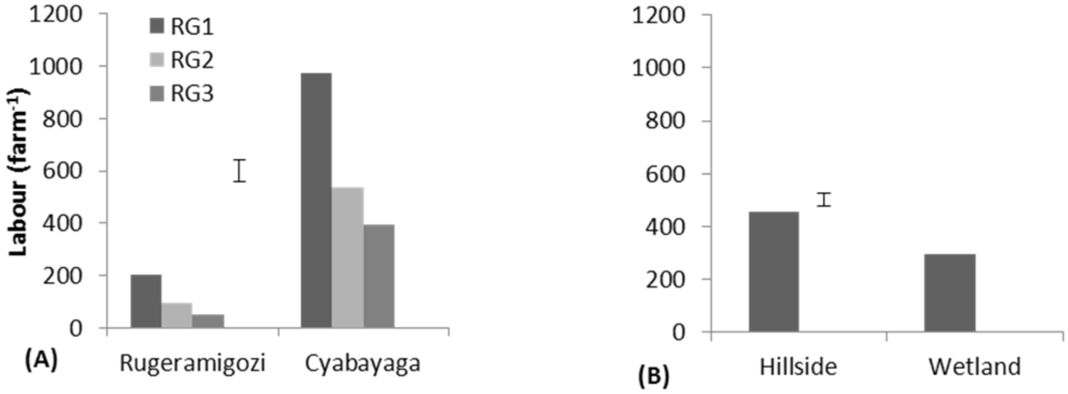


Figure 5.4. Annual number of labour days used in Rugeramigozi and Cyabayaga by different resource groups (A) and niches (B). Vertical bars represent the standard error of the differences (S.E.D).

In general gross margin in both sites were statistically different between niches and within wealth classes (Figure 5.5A). Only in Rugeramigozi the gross margin from the wetland cultivation of the rich households were not statistically different (P>0.05) from those of moderate households. This observation may be due to the fact that land size in Rugeramigozi wetland of the moderate and rich farmers is the same. The crop incomes were highest from the wetland (P<0.001) in Cyabayaga whereas in Rugeramigozi, the higher income came from the hillside fields (P<0.001) (Figure 5.5A & B).

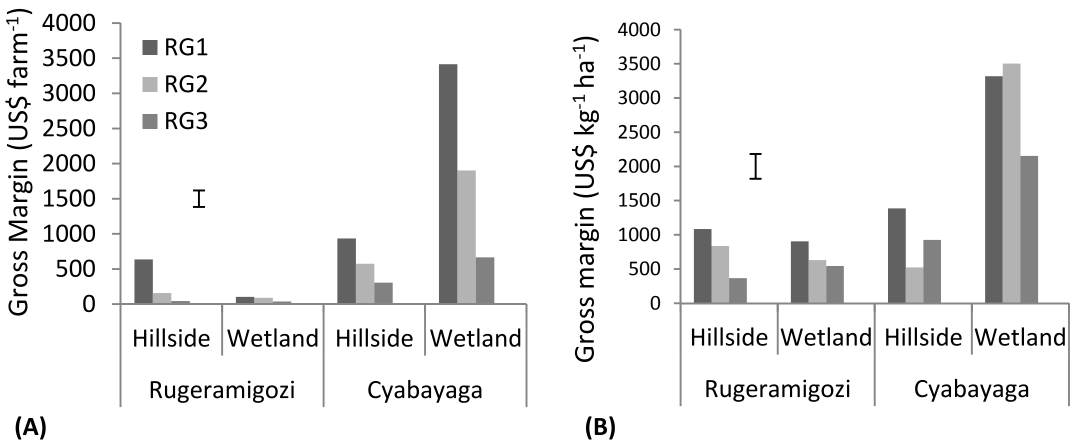


Figure 5.5. Annual gross margin earned for different resource groups farm, from Hillside and Wetland fields in Rugeramigozi and Cyabayaga. (A) Average gross margin per farm (US$); (B) average gross margin per hectare (US$). Farms were classified according to a typology (farm types 1-3). Vertical bars represent the standard error of the differences (S.E.D) of the interaction between sites, niches and different resource groups farm.

5.3.3 Nutrient fluxes in Rugeramigozi and Cyabayaga catchments

Nutrient Inputs

The higher input of nutrients in Cyabayaga compared to Rugeramigozi and in wetland compared to hillsides (Figure 5.6) can be explained by the use of inorganic fertilizer and rice straw compost on rice in Cyabayaga wetland. The PRA showed that farmers were recently sensitised to compost the rice straw in Cyabayaga and reuse it in the subsequent season at the same field. This practice also enhanced nutrients inputs in the wetland. Furthermore, in wetlands farmers are grouped into cooperatives and consolidate agricultural production which favours the use of input for crop production. Figure 5.6 shows that the rates of input use were higher for the wealthier class of farmers (P<0.05). They use more inorganic manure and have more livestock and hence more organic manure. This observation explains the relatively better soil fertility of fields of the wealthier classes (Figure 5.2).

According to farmers, cow dung and household compost manure application are the most important sources of nutrient inputs in crop plots in Rugeramigozi and on hillsides in Cyabayaga. This underscores the importance of organic manure in agricultural systems in Rwanda. However, according to farmers in Cyabayaga, limited animal manure is applied to hillside plots. One possible reason is that sometimes cattle in Cyabayaga graze in communal lands. Furthermore, farmers in Cyabayaga perceive that their land is fertile and indicate water availability as their major production constraint.

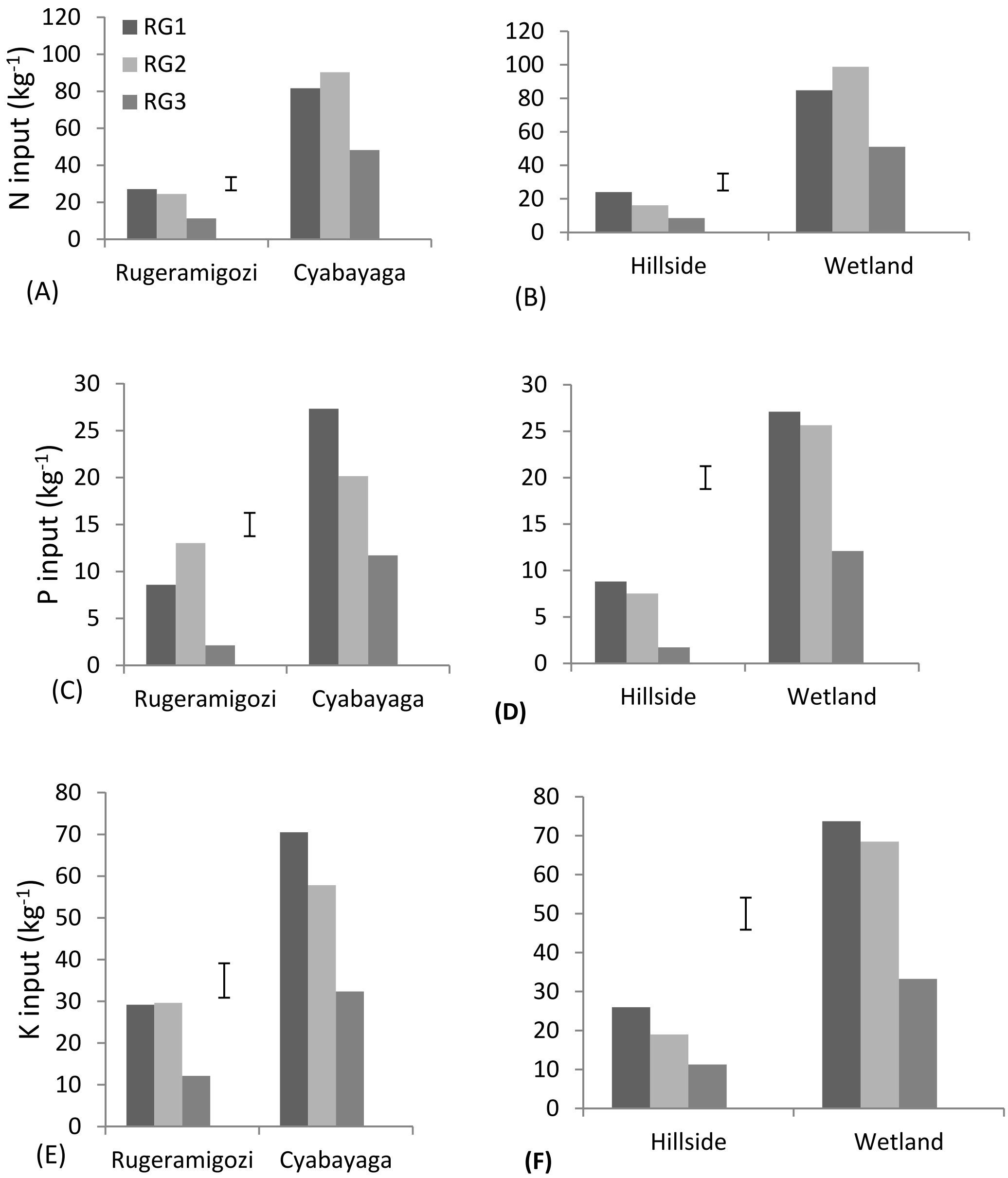


Figure 5.6. Annual nutrients input for rich (RG1), moderate (RG2) and poor (RG3) resource groups and in different niches in Rugeramigozi and Cyabayaga. (A) N inputs per resource group in Rugeramigozi and Cyabayaga; (B) N input in wetland and hillside per resource group; (C) P input per resource group in Rugeramigozi and Cyabayaga; (D) P input in wetland and hillside per resource group; (E) K input different resource group in Rugeramigozi and Cyabayaga; (F) K input in wetland and hillside per resource group. Resource groups were classified according to a typology (farm types 1-3). Vertical bars represent the average standard error of the differences (S.E.D) of the interaction between sites or niches and resource group farm.

Nutrient Outputs

Nutrient outflow was statistically higher ($P<0.05$) in Cyabayaga compared to Rugeramigozi and in the wetlands compared to hillsides (Figure 5.7 B, D and F) ($P>0.05$). The mean N, P and K output from Rugeramigozi wetland were generally less than half of the nutrient output in wetland plots in Cyabayaga. A possible reason is that households are relatively poor in Rugeramigozi compared to Cyabayaga. Output fluxes decreased with decreasing access to resources. In general, the poor resource farmers have lower output compared to moderate en rich resources groups s ($P<0.05$) (Figure 5.7). The higher output observed in wetlands and with the moderate and rich classes may be caused by the market oriented crop production in wetlands and the wealth status of farmers, which results in removal of nutrients from the farm household system.

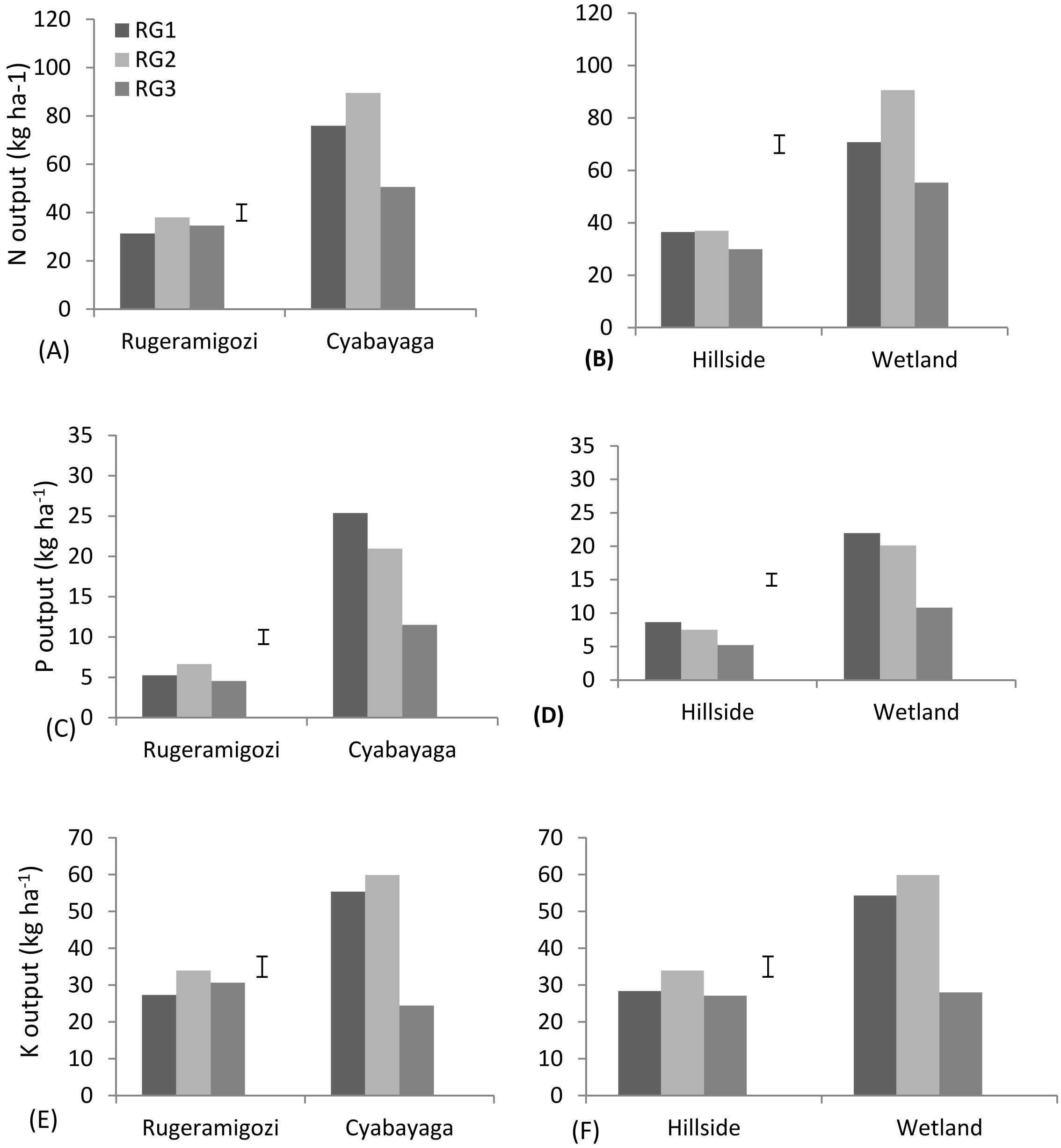


Figure 5.7. Annual nutrients outflow for different resource group farm and niches in Rugeramigozi and Cyabayaga. (A) N outflow for different resource group farm in Rugeramigozi and Cyabayaga; (B) N outflow in wetland and hillside for different resource group farm; (C) P outflow for different resource group farm in Rugeramigozi and Cyabayaga; (D) P outflow in wetland and hillside plots for different resource group farm; (E) K outflow for different resource group farm in Rugeramigozi and Cyabayaga; (F) K outflow in wetland and hillside for different resource group farm. Farms were classified according to a typology (farm types 1-3). Vertical bars represent the average standard error of the differences (S.E.D) of the interaction between sites or niches and resource group farm.

The highest export of N, P and K was observed in Cyabayaga wetland. This is consistent with the high grain yield for rice in this wetland. Actual rice grain yields were as high as 5000 kg ha^{-1} in the studied households compared to a national average of 4400 kg ha^{-1} in Rwanda. Therefore, a significant amount of nutrients are lost from the wetland plots through crop harvest. There are more nutrient losses in Cyabayaga wetland because of relatively higher soil nutrients levels (Figure 5.2) and the use of fertilizer (section 5.3.3, Nutrient inputs).

Partial Nutrient Budgets

Generally, partial N, P and K balances in hillsides were more negative (P<0.05) for crop plots in Cyabayaga than in Rugeramigozi (Figure 5.8A, B&C). Furthermore, limited nutrient inputs are applied to hillside plots in Cyabayaga compared to Rugeramigozi (Figure 5.6).

Between hillsides and wetlands, N and P partial balance were not significantly different (P>0.05)in Rugeramigozi (Figure 5.8A&B).Although farmers are organized in cooperatives and are required to use inputs on crops in wetlands, most of the nutrients are exported through harvest and crop residues for forage. Nevertheless, while rich and moderate resource groups have partial positive balances of P for both hillside and wetland fields and K also positive in wetland fields, the poor resource groups were experiencing anegative balance for N, P and K in both Cyabayaga and Rugeramigozi on hillsides (Figure 5.8).

The Cyabayaga wetland showed a strong positive partial balance for N, P and K (Figure 5.7 A, B & C). The causes of higher levels of nutrient balance in the Cyabayaga wetland were related to the input of nutrients.

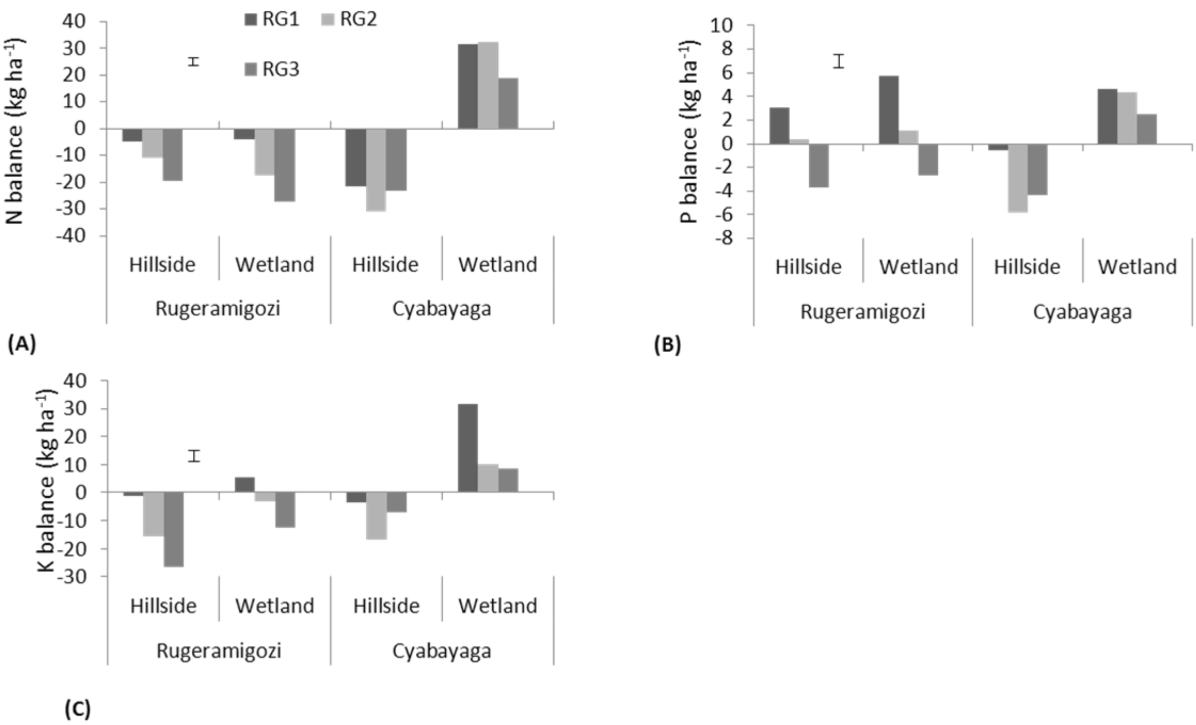


Figure 5.8. Annual nutrients partial balance. (A) Partial N balance plots for different resource group farm and niches in Rugeramigozi and Cyabayaga; (B) Partial P balance in wetland and hillside plots for different resource group farm in Rugeramigozi and Cyabayaga; (C) Partial K balance in wetland and hillside plots for different resource group farm. Farms were classified according to a typology (farm types 1-3). Vertical bars represent the standard error of the differences (S.E.D) of the interaction between sites, niches and different resource group farm.

5.4 Discussion

Livestock, gross margin per ha, wealth classes, agricultural niches and sites are important determinants of partial nutrient flows and balances in Rwanda; however, farm size showed negative influence only on the N balance (Table 5.2). Contrary to other findings (e.g. Nkonya et al., 2005), availability of labour does influence neither nutrients flows nor nutrient balances in this study although there is evidence of shortage of labour in Cyabayaga (Table 5.2). These observations may be due to the confounding factor with the use of inorganic fertilizer in Cyabayaga wetland.

Table 5.2. Regression coefficients of determinants of soil nutrients flows in Rugeramigozi and Cyabayaga.

Determinants of nutrients	Inflows			Outflows			Partial Balance		
	N	P	K	N	P	K	N	P	K
Farm size (ha^{-1})	-12.4^{ns}	1.2^{ns}	-2.0^{ns}	-4.4^{ns}	1.4^{ns}	-1.4^{ns}	-7.9*	0.5^{ns}	-5.0^{ns}
Ln (labour used)	5.3^{ns}	1.1^{ns}	4.6^{ns}	0.3^{ns}	-0.4^{ns}	6.8^{ns}	5.3^{ns}	0.9^{ns}	4.0^{ns}
Tropical livestock unit (TLU)	22.6**	1.7^{ns}	11.2*	16.6**	0.8^{ns}	6.2^{ns}	6.3***	2.0**	3.7***
Ln (Gross margin ha^{-1})	35.4***	9.3***	24.1***	16.2***	7.5***	16.0***	19.5***	2.4***	3.8*
Class 2 (moderate poor)	27.6**	3.1^{ns}	10.1^{ns}	26.0**	-0.6^{ns}	15.8**	2.0^{ns}	0.03*	-9.0***
Class 3 (poor)	34.2**	-0.8^{ns}	10.6^{ns}	24.4*	-3.4ns	12.0^{ns}	11.3**	1.2ns	-6.2*
Niches(1=hillside , 0=wetland)	-25.0***	-8.1***	-18.3**	-19.1***	-3.8**	-4.7^{ns}	-6.0*	-3.0***	-14.1***
Sites (1=Rugeramigozi 0=Cyabayaga)	-33.9***	-4.0^{ns}	-10.8^{ns}	-31.2***	-8.7***	5.3^{ns}	-2.0^{ns}	3.4***	-8.3*
Constant	-451.5***	-110.2***	-304.8***	-166.6*	-76.6***	-222.5***	-291.6	-38.3***	-58.1*
Observations (n)	108	108	108	108	108	108	108	108	108
Prob>F	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
R-squared	0.81	0.67	0.60	0.66	0.71	0.42	0.83	0.67	0.73

Asterisks denote associated coefficient is significant at: P<0.05 (*); P<0.01 (**) and P<0.001 (***); ns: non-signicant.

When relating gross returns to nutrients flux, a significant, strong positive relation is found for input, output and partial balance (Table 5.2). Both higher external inputs use and a higher nutrient balance can be attained through increasing gross margins and a shift from low return crops to high-value crops such as rice and vegetables. Since more rice is produced in Cyabayaga wetland than in Rugeramigozi wetland, more fertilizers were applied in Cyabayaga wetland compared to Rugeramigozi wetland (Figure 5.5A, B&D). Although rice is becoming an important food crop in Rwanda; it is mainly produced for the market. The price of rice has been increasing at international level which has contributed to increasing price for rice in Rwanda (MINAGRI, 2008). Since they are assured of its market, farmers are willing to apply inorganic fertilizers to rice. Rice is a policy priority crop and the government assists farmers through capacity building on rice agronomic practices, the use of subsidized inputs and the control of the price of rice (Kagabo et al., 2010) which lead to higher productivity.

The resources farmers invest in soil fertility improvement are highly dependant on the potential increase in agricultural production, as well as what resources are available for the farmer to invest. However, transition to more sustainable production is more likely when the risk associated with the cultivation of certain high-value crops is reduced, for example, through the introduction of adapted varieties tolerant to low soil fertility. According to Nabahungu and Visser (2011a, ch 3), the introduction of high marketable rice failed in Rugeramigozi due to low adaptability to local conditions. Furthermore, the enhancement of economic incentives, such as well-developed input -outputs markets for agrochemicals such as inorganic fertilizers, decreases soil mining. This is in line with findings by Sissoko (1998) and Kruseman (2000), which show that input and output price incentives, as well as credit facilities, can reduce the intensity of soil mining. Other policies aimed at improving access to commodity price information in rural areas, as well as credit facilities to enable cultivation of high value crops are potential in improving sustainability of cropping system.

In general, although plots in wetland are far from homestead, wetland fields report significant higher nutrients balances than those in the hillsides (Figure 5.7A, B&C), suggesting that crop production in wetlands is more sustainable than in hillsides. Wetlands are considered to be a high potential area due to the moisture availability throughout the year. Furthermore, wetlands are considered to have relatively good soils compared to their surrounding hillsides (Nabahungu and Visser, 2011b, ch 4), even though wetlands like Rugeramigozi have a lower soil fertility status than its surrounding hillsides (Figure 5.2). Another factor which influences the higher input in wetland fields compared to the hillside fields is that farmers cultivating wetlands are grouped in cooperatives and they have to follow the directives of the cooperative and of the extension services of the districts (Nabahungu and Visser, 2011a, ch 3). It is evident that farmers tend to focus on specific crops rather than on the sustainability of the entire farming system. This strategy results in a simultaneous increase or even over-supply of nutrients on some fields and depletion on other fields. This may be a threat to long-term sustainability of the system. The problem in Cyabayaga wetland can be seen differently as soil nutrients concentration may cause eutrophication. However a full nutrient balance is needed to confirm this hypothesis.

Ownership of livestock (as measured by TLU) increases N and K inputs and N output and has positive correlation with the partial balance of N, P and K (Table 5.2). Farmers with livestock have manure to use for crop production. Furthermore, livestock is a source of income, which can be used to buy either inorganic fertilizer and/or farmyard manure. In the study areas, zero grazing is mostly practiced and farmers use crop residues as animal feed. Hence, there is a high transport of nutrients from the crop fields to animals. The animal manure is applied to crop fields to improve soil fertility. However, during the conversion of feed to animal products, there is substantial loss of energy, water and nutrients (Rutunga et al., 2007). Furthermore, during composting, storage and handling system there is also a loss of nutrients (Rutunga et al., 2007). Therefore, the nutrient cycling from crops to animals and manure from animals to crops has the potential to render the system unsustainable in future despite the synergy advocated in agricultural systems.

Although, there is a loss of nutrients during the conversion of feed to animal products, farmers with livestock increase nutrients balance on their farms through the use of extra residues from poor farms and through purchasing fertilizer. According to the PRA, households with a larger number of livestock applied more manure. This is consistent with the general observation in sub-Saharan Africa, where cattle ownership implies more manure available for application on the farms (Bationo et al., 1998; Nandwa and Bekunda, 1998; Vanlauwe and Giller, 2006; Zingore et al., 2007).

Different resource endowment had a clear impact on nutrients fluxes on N and K (Table 5.2). Plots of wealthier farmers usually had higher nutrient balances (Figure 5.7A, B&C). A group of rich farmers had a stronger orientation on cropping activity associated with high gross margins and sustainability. Such farmers are associated with positive or nearly positive soil nutrients balances (Figure 5.7). They also have higher levels of input use, and reduced or even reversed levels of soil mining. This is explained by the possibility of wealthier farmers to invest in soil fertility (Cobo et al., 2009), sometimes at the expense of poor farmers (Zingore et al., 2007); i.e. nutrient fluxes from the poor farmers' fields to the rich farmers' livestock and for mulching. According to the FAO (1990), large resource availability determines the potential to acquire more farm resources for crop and livestock production by transforming the outputs into inputs for different enterprises in the agricultural system. Further enhancement of market functioning and profitability of their farm production, given the importance of high return to crop due to input use, will most strongly benefit this group. Poor resource households in both study sites do not have cattle. This implies that these poor resource households lack manure to apply on their crop. Furthermore, poor resource households in Cyabayaga are losing nutrients to rich resource households by allowing cattle to graze in their plots.

Although in Rugeramigozi the relatively high rainfall provides opportunities for crop diversification, land shortage, the lack of adapted high value crops (Nabahungu and Visser, 2011a, ch 3) and the low fertility status of the fields lead to low production. According to many authors (Pottier, 2006; Huggins, 2009; Ansoms and MacKay, 2010; Nabahungu and Visser, 2011b, ch 4), insufficient access to land is the most critical factor to food insecurity in Rwanda. Drechsel et al. (2001) stated that the rapidity of soil degradation depends on local soil fertility levels, and vary with farmers' possibilities and constraints for soil conservation and nutrient replenishment. For example, the yield in 2008 was 500 kg ha^{-1}, which is approximately half of the average sorghum yield of 1100 kg ha^{-1} in Rwanda (MINAGRI, 2008). Furthermore, the organic manure applied in Rugeramigozi is not enough to avert the poor soil fertility hence poor crop production. Addition of organic manure and compost would improve the physical and chemical properties of soils with low CEC and pH, but it is easier to recommend the use of organic matter than to implement it especially because organic residues are scarce and have competing demands (e.g. for livestock and fuel). Therefore, supplementing organic with inorganic fertilisers is indispensable in the farm households systems. Because of low resource endowment, households in Rugeramigozi concentrate on food crop production in their hillside plots. The intervention of the policy in Rugeramigozi like the subsidy of fertilizer is very difficult due to small land parcels (Figure 5.2A) and likely limited nutrients response (Figure 5.2) due to the low pH and carbon content. Correcting the soil pH and raising the organic matter content of the soils through the use of liming materials and organic manure respectively will ensure the current crop intensification policies in the country benefit this group, because production risks will have been reduced significantly. This finding should guide agricultural research and development organisations in improving cropping systems and designing policies aimed at enhancing sustainable use of land resources by the poorest farmers.

A full nutrient analysis is required to fully understand the dynamics of nutrients within the wetlands farm systems in order to build a strong basis for evaluating the sustainability of these systems. For example, N_2 fixation from bush bean used in rotations with cereals in Rugeramigozi wetland was underestimated because of limited data availability. However, incorporating these nutrient flows in subsequent calculations should be taken care of when using the underlying assumptions. Transfer functions are used for calculating losses for processes that are difficult to quantify e.g. gaseous losses due to denitrification. Faerge and Magid (2004) observed that transfer functions often overestimates nutrient losses due to denitrification because nutrient flows in this process are based on assumed rate of mineralization.

5.5 Conclusions and recommendations

Results showed clear effects of site and farmer resource group on management, nutrient balances and profitability of the studied field types. More labour intensity and nutrient resources were allocated to wetland plots to maximize production for sale. Cash crops are mainly grown in the wetlands to maximize the continuous availability of moisture and fertile soils. In contrast to many studies which identified closer fields as zones of nutrient accumulation and distant fields as zone of nutrient depletion, results from the landscape scale show that the nutrients balances depend on the crop grown and intensity of soil management practices.

The level of farm income is a critical factorwhich affects households' ability to invest in land management, and their ability to recoup those investments by marketing higher value agricultural products. Some segments of society, especially those with the smallest farms and poor households, are disproportionately affected by soil degradation and are the least able to address the problem. They would require particular attention, from a social/ policy and economic standpoint.

Lower inherent soil fertility, shortage of land and the lack of adapted high value crops led to a spiral of low productivity/ low investments/ increased soil degradation in Rugeramigozi. Farmers do not have the resources themselves to break this cycle without economic and policy assistance. Therefore, the processes that impact on land management and land degradation in Rwanda are tied to economic, social and agricultural policy. Addressing land degradation willrequire not simply technical solutions but also changed and improved economic and social conditions.Programs to prevent and mitigate land degradation will therefore need to be conducted within a broad economic development plan that includes the agricultural and non-agricultural sectors.

Chapter 6

Improved agricultural productivity of wetlands through fertilizer use and N fixation enhancement

This paper is under review as:

Nabahungu, N.L., Vanlauwe, B. and Stroosnijder, L., 2011. Improved agricultural productivity of wetlands through fertilizer use and N fixation enhancement. Submitted to: Field Crop Research.

Improved agricultural productivity of wetlands through fertilizer use and biological N fixation in Rwanda

Abstract

Integrated soil fertility management (ISFM) involving a nitrogen-fixing grain legume, farmyard manure (FYM) and limited amounts of fertilizer can enhance grain legume and maize productivity. Limited knowledge is available on the performance of ISFM practices within the context of Rwandan landscapes. A multi-locational trial was laid out at two sites (Rugeramigozi in Southern Rwanda, Cyabayaga in Eastern Rwanda) on three landscape positions (valley bottoms, footslopes and hillsides) with between 4 and 17 replications per landscape positions. Each trial contained 2 factors (cropping system and fertilizer application) laid out as a randomized complete block design. The cropping system factor contained three levels: continuous maize-maize, bean (*Phaseolus vulgaris* L.) -maize (*Zeamays*L.) rotation, and soybean (*Glycinemax*(L.) Merr.)-maize rotation. Fertilizer application contained three levels: no fertilizer, FYM and FYM + diamonium phosphate (DAP) applied only in the first season. N-fixation of bean and soybean was assessed using the 15N natural abundance method.Maize grain yield was 2.6 t ha^{-1} in Rugeramigozi and 4.2 t ha^{-1} in Cyabayaga. Beans had highest yields in Rugeramigozi (0.7 t ha^{-1}), while soybean in Cyabayaga was most successful (1.4 t ha^{-1}). In general legume and maize yields were lowest on the hillside plots. Fertilizer application increased grain yield, shoot dry matter and N accumulation of both legumes and maize with the highest yield observed in the treatment combining FYM and DAP. Nitrogen fixed was < 30 kg ha^{-1}. Maize yield after legumes was higher than continous maize production for the two seasons studied. The N balance was negative in both sitesat all landscape positions and under all fertilizer applications.This proves that maize yield response after legumes is not only attributable to improvements in soil N supply through N fixation but that there are residual and indirect effects.

6.1 Introduction

In Rwanda, the productivity of the agricultural land on hillsides is no longer sufficient to provide food security for the majority of poor farmers (Ansoms and McKay, 2010) due to (i) dramatic changes in farm size, currently on average less than one hectare, (ii) soil erosion processes and (iii) the limited use of fertilizer. The response by Rwanda's farmers to these trends has been to expand their agricultural activities into fragile wetlands (Nabahungu and Visser, 2011a, ch 3). The cultivation of marginal lands and the large scale reclamation of the wetlands have led to the degradation of these resources, with the risk of losing their productive capacity. According to Nabahungu et al. (2011c, ch 5), the rapidity of soil degradation depends on local soil fertility levels, and varies with farmers' possibilities and constraints for soil conservation and nutrient replenishment. Without investment in land improvement, soil degradation will continue, leading to low agricultural productivity and hence to increased food insecurity and reduced cash income. In 2008, the government of Rwanda (GoR) launched in a crop intensification program aiming at mobilizing farmers to adopt new farming methods, including the use of improved varieties, fertilizers and pesticides (REMA, 2009). Maize is a priority crop in the crop intensification program. However, the use of inputs is still limited to a few farmers in Northern Rwanda growing potatoes and to farmers growing rice in wetlands (Naramabuye et al., 2009).

In sub-Saharan Africa (SSA), the development and deployment of cost-effective nutrient supply strategies for smallholder farmers remain a major challenge. In the highland agricultural ecozones of SSA, N supply is a key limiting factor in crop production for 35–45% of the farmers (Odame, 1997). Many SSA countries have a growing need for fertilizers to enhance crop yields (Mugabe, 1994; Morris et al., 2007; Chianu et al., 2010). However, the majority (about 60%) of African smallholder farmers are unable to afford the high prices of mineral fertilizers (Yanggen et al., 1998). Furthermore, more than 75% of the mineral fertilizers used in Africa are imported (Mugabe, 1994), requiring investments in foreign exchange. The integration of N-fixing grain legumes such as dual purpose promiscuous soybean and beans combined with a moderate level of fertilizer into maize-based systems has been reported to greatly enhance maize productivity and the sustainability of the production systems in Africa (Sanginga et al., 2003). Soybean can fix up to 80% of its N needs (Smaling et al., 2008). Promiscuously nodulating soybean also provides residual soil-N to maize in rotation, in addition to providing the farmers with seeds and fodder for food and feed, and income from the marketing of these products (Vanlauwe et al., 2001, Sanginga et al., 2003). Legumes also have additional benefits of controlling nematodes and the noxious parasitic weed (*Striga hermonithica*) (Weber et al., 1995; Carsky et al., 2000). Within legume-cereal cropping systems, Giller (2002) postulated that maximizing N_2 fixation also has an effect on residual P for the subsequent cereal crop. Phosphorus (P) application to a legume phase was hypothesized to have the potential to increase legume efficiency in accessing and solubilising P through enhanced root growth and release of organic exudates (Kihara et al., 2010). Although, supplementing legumes with soil nutrients has been shown to increase yields (Dakora, 1984; da Silva et al., 1993), plant growth, and N_2-fixation compared with the unfertilized control (Ndakidemi et al., 2006), legumes, smallholder farmers rarely apply fertilizer to legumes, unlike cereals, probably due to the high cost of fertilizer and low awareness of the associated economic returns (Ndakidemi et al., 2006). Grain legumes are also seen as the ‘meat for the poor’ due to their high protein content and their low price, compared with meat. However, the average yields of grain legumes have remained very low under farmers’ conditions. According to Musoni (2008), on-farm productivity of beans in Rwanda, averaging 800 kg ha^{-1}, is low and is 4-5 times less than the potential yield obtained under on-station conditions. Low yields are associated with declining soil fertility due to continuous cropping without soil replenishments and reduced N_2-fixation due to various biological and environmental factors (Dakora and Keya, 1997). This becomes more severe as farmers expand into marginal lands in response to population pressure.

Currently, both climbing and bush beans are intensively cultivated in Rwanda on about 30% of the arable land (Musoni, 2008). However, Rwanda imports about 60,000 ton of additional bean grains annually from the neighbouring countries in order to meet the additional internal consumer demand (Ferris, 2002). This is partly caused by elevated annual per capita consumption of 50 - 60 kg, one of the highest in the world. Ferris (2002) and MINAGRI (2004) have projected the demand for beans to double by the year 2020, if the current production trends do not improve. Although, the indeterminate morphology and architecture of the climbing beans are positively associated with high yield potential of 3 to 5 t ha^{-1} (three-fold the yield of the bush beans) (Sperling et al., 1992) and high biological N fixation potential, climbing beans are intensively cultivated only in the higher altitude zones in Rwanda beyond 1700 m a.s.l. Cultivation of promiscuous soybean can partially substitute bush bean production to improve productivity and soil fertility in rotation with maize in middle and low altitude in Rwanda. Benefits of soybean over common bean, commonly grown by smallholder farmers in Rwanda, include lower susceptibility to pests and disease, better grain storage quality, and a larger aboveground biomass which gives a soil fertility benefit to subsequent crops (Mpepereki et al., 1996). According to Mpepereki et al. (2000), promiscuously nodulating varieties have been developed which nodulate and fix nitrogen under smallholder farmers’ conditions without inoculation, which make these more appropriate for smallholder farmers. However, limited studies are available on the contribution of grain legumes to the N balance in maize-based systems in Rwanda as affected by application of limited amounts of organic inputs and fertilizer. Therefore, the identification of innovative strategies for the development of an ISFM package, including promiscuous grain legumes, can enhance legume-maize system productivity in resource limited smallholder farmers.

In Rwanda, soils vary over short distances in response to relief, parent material and altitude. Soil parameters change in a characteristic way from the hilltop/upper slope to the footslopes and wetlands and these variations in soil parameters are often reflected in crop yields (Steiner, 1998). They also influence the response of crops to fertilizer application and the biological N fixation capacity of legumes (Steiner, 1998). Any evaluation of ISFM strategies needs to necessarily take into account this biophysical variability to ensure that the obtained information is applicable to the farming environment of smallholder farmers.

The objectives of this study were: (i) to evaluate the impact of organic inputs and fertilizer on soybean and common bean yields and N fixation under different landscape positions, (ii) to assess the impact of legume productivity on a subsequent maize crop, and (iii) to assess their contribution to the N partial N balance in legume-maize systems in Southern and Eastern Rwanda. We hypothesize that ISFM practices, involving the integration of appropriate dual purpose grain legumes, with limited amounts of organic inputs and fertilizer, may result in synergistic effects in enhancing maize productivity in Rwandan landscapes.

6.2 Materials and methods

6.2.1 Sites description

The Cyabayaga and Rugeramigozi wetlands (Figure 6.1) were selected as representatives for typical wetland agriculture in Rwanda(MINAGRI, 2002). The Cyabayaga wetland is located in Nyagatare district (1°22' 51.6" S, 30° 17' 07" E), Eastern Province of Rwanda, has an surface of 1080 ha, and is part of the eastern savannah agro-ecological zone lying about 1400m a.s.l. The Rugeramigozi wetland is located in Muhanga District(02° 07’ 40’’ S, 29° 45’ 20’’ E), Southern Province, covers an area of 225 ha, and is located on the plateau agro-ecological zone of Rwanda at around 1650m a.s.l. Annual rainfall is 1200 - 1400 mm in Rugeramigozi and 800 - 1000 mm in Cyabayaga. The rainfall pattern in Rwanda is bimodal (Figure 6.2) with the short, most important and reliable rainy season from September to January (named Season A). The long rains are from mid-February to May (Season B) and have high rainfall intensity. The surrounding catchments of both wetlands are characterized by gently sloping hillsides, gradually converging into wetlands. Villages in the hillsides consist mainly of scattered households and farmers have fields both in the hillside and in the wetlands. Since the beginning of the 19th century until official reclamation, the wetland was cultivated only in the dry season (Season C) from June to September but nowadays farmers cultivate the wetland throughout the year.

The two study sites represent two important types of wetlands used for agriculture. Rugeramigozi lies in the highly populated central plateau zone of Rwanda where pressure on land is high. Hillside soils are infertile but rainfall is relatively high and reliable. Wetlands are absolutely essential components of rural livelihoods because land pressure is high on the hillsides and because wetland soils are relatively more productive. Cyabayaga wetland is a new reclaimed land, and therefore has a higher fertility level than Rugeramigozi (Table 6.1).

Table 6.1. Selected soil Characteristics of the Rugeramigozi and Cyabayaga catchments. Numbers in bracket represent standard deviations.

Sites	Landscape positions	pH water	pH KCl	Organic C	Total N	Bray-1 P	Exchangeable K	Clay	Silt	Sand
				%		mg kg^{-1}	cmol$_c$ kg^{-1}		%	
Rugeramigozi	Hillside	4.8 (0.2)	4.4 (0.2)	1.8(0.4)	0.13(0.02)	18.9(9.9)	0.7(0.3)	26.9(11.5)	8.5(3.2)	64.6(9.8)
	Footslope	4.5(0.2)	4.1(0.2)	1.6(0.3)	0.12(0.02)	7.9(3.2)	0.3(0.2)	28.2(9.3)	13.5(4.6)	58.3(7.7)
	Wetland	4.3(0.2)	4.1(0.2)	1.7(0.4)	0.11(0.03)	6.9 (3.7)	0.3(0.2)	28.0(8.0)	16(7.0)	57.0(11.0)
Cyabayaga	Hillside	5.5(0.1)	5.1(0.1)	2.3(0.4)	0.17(0.02)	30.6(23.6)	1.3(0.6)	27.3(5.0)	8.7(4.5)	64.0(8.3)
	Footslope	5.8(0.2)	5.3(0.2)	4.5(1.5)	0.33(0.10)	20.2(5.6)	1.1(0.3)	27.8(6.2)	17.5(3.8)	54.7(4.2)
	Wetland	5.8(0.2)	5.2(0.2)	5.0(2.0)	0.39(0.18)	29.5(15.2)	0.3(0.2)	29(6.0)	17(6.0)	54.0(9.0)

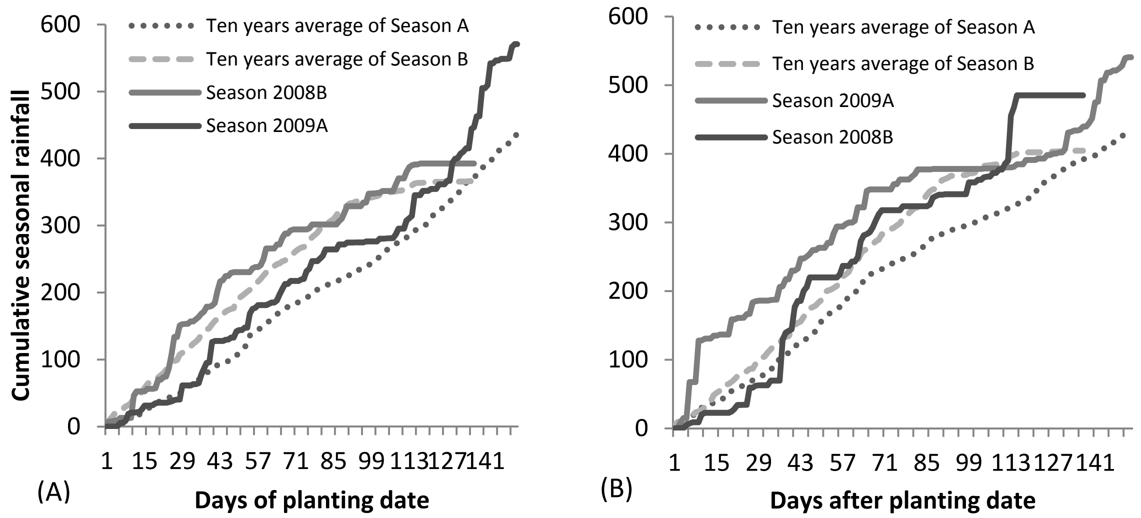


Figure 6.1.Ten years cumulative seasonal rainfall at experimental sites, (A)in Rugeramigozi; (B) in Cyabayaga.

6.2.2 Experimental design and plot establishment

The trials were laid out in farmers' fields and were researcher-managed. In Rugeramigozi and Cyabayaga, a factorial design with cropping system and input application as factors was laid out in three landscape positions, namely on hillside, footslope and in wetlands. The trial was replicated 8, 6 and 7 times on hillside, footslope and wetland respectively in Rugeramigozi whilst in Cyabayaga the replications were 17, 6 and 9 times respectively on hillside, footslope and wetland. The cropping system factor contained three levels: continuous maize, bean-maize rotation and soybean-maize rotation and the input application also contained three levels: no fertilizer application, FYM and FYM + DAP applied in season 1(Table 6.2). FYM was applied at 3 t ha^{-1} dry matter basis and DAP at 100 kg ha^{-1}. FYM manure was broadcasted and then mixed with soil using hand hoe whilst DAP was banded within the line. Varieties used were for beans (*Phaseolus vulgaris* (L.): variety RWK 10, for soybean (*Glycine max* (L.) Merr.): variety Maksoy 1a (locally referred to as SB24), and for maize: variety ZM 607, recommended for low and middle altitudes in Rwanda. The legume varieties were selected from a legume screening trial in Eastern province (CIALCA, 2008).Soybean was used as a dual-purpose grain legume based on its potential in biomass and grain production and its soil fertility restoration potential through N fixation. Soybean was planted at 0.75 m inter-row and 0.05 m intra-row spacing, while beans were spaced 0.5 m inter-row and 0.10 m intra-row. Maize was planted at 0.25 m (between plants) by 0.75 m (between rows) with two seeds per planting hole and thinned to one plant per hole. Plot size was 5m x 4m. Two weeding operations using a hand hoe were done in both legumes and maize plots. Legume and maize residues in the first season were left on the field and incorporated during subsequent land preparation.

6.2.3 Biomass production assessment

All the legume plots were sampled to determine aboveground legume biomass production at mid pod filling stage, near maximum dry matter accumulation. Biomass was determined by destructive sampling of plants in a 0.5 m by 0.5 m quadrat in three randomly selected positions within each plot, excluding the border rows. Biomass was immediately weighed in the field to determine fresh weight and then divided into two sub-samples. One subsample was weighed with an electronic balance and then oven-dried at 65 ^{0}C for 4 days to determine dry weight and moisture content, which were used to calculate dry matter production. The other subsample was processed and used for quantification of N_2-fixation.

Table 6.2. Treatment structure of the multi-locational trails laid out in the Rugeramigozi and Cyabayaga catchments in Rwanda.

Cropping system	Fertilizer	Season 1	Season 2
Continuous maize	No input	Maize	Maize
	FYM	Maize	Maize
	FYM + DAP	Maize	Maize
Bean-Maize rotation	No input	Bean	Maize
	FYM	Bean	Maize
	FYM + DAP	Bean	Maize
Soybean-maize rotation	No input	Soybean	Maize
	FYM	Soybean	Maize
	FYM + DAP	Soybean	Maize

DAP= Diamonium phosphate, application rate was 100 kg ha^{-1}, FYM = Farmyard manure, application rate was 3 t ha^{-1} dry mass basis.

6.2.4 N_2-fixation methodology and calculations

The proportion of legume N derived from N_2-fixation was determined using the ^{15}N natural abundance method (Peoples et al., 1989). This method is based on the principle that the^{15}N enrichment ($\delta^{15}N$) of the plant-available soil N differs from that of atmospheric N_2. The %N from N-fixation calculated using the equation of Shearer and Kohl (1986) and Peoples et al. (1997)according to equation 6.1.

$$\%N \text{ from } N_2 - fixation = 100\ (\delta^{15}N_{ref} - \delta^{15}N_{legume} / \delta^{15}N_{ref} - B) \qquad [6.1]$$

Where:

$\delta^{15}N_{ref}$ is the ^{15}N natural abundance of the shoots of a non-N_2-fixing reference plant deriving its entire N from the soil N.

$\delta^{15}N_{legume}$ is the ^{15}N natural abundance of the shoots of the N_2-fixing legume plant growing in the same soil.

B is the ^{15}N of the test legume fully dependent on N_2-fixation for growth, and a correction for isotopic fractionation during N_2-fixation.

The legume shoot samples were air-dried to constant weight, ground to <1 mm in an electric mill in preparation for ^{15}N analysis. The ^{15}N analysis was done at the UC Davis Stable Isotope Facility, CA, USA, using a PDZ Europa 20–20 mass spectrometer. The ^{15}N natural abundance of the samples was computed using the equation of Shearer and Kohl (1986) as follows:

$$\delta^{15}N\ (\%_o) = 1000\ [(R_{sample}/R_{standard})-1] \qquad [6.2]$$

Where:

$\delta^{15}N$is the ^{15}N natural abundance of the samples expressed as parts per thousand;

R is the ration of $^{15}N/^{14}N$ in the sample;

the atmospheric N_2 was used as the standard (Standard).

By definition, the δ15N of the atmosphere is zero. A range of broad-leaved weed plants and maize, growing in the same fields as the legumes, were used as reference plants, while B values were obtained from Ojiem et al. (2007) (B value of soybean= -2 and B value for bean = -1).

6.2.5 Grain production assessment
Maize and legumes grain yields were assessed in all trials. The pods and cobs were sun-dried for several days and then threshed. Maize and legumes grain were then weighed and grain moisture content determined using an electronic moisture meter. Grain yields were calculated at 12% moisture content.

6.2.6. Statistical analysis
Data analysis of variance (ANOVA) was done using the mixed procedure (REML) in Genstat version 13.2. Data were analysed by landscape position, by site and across sites. Sites, landscape position, crops and fertilizers were considered as fixed effects while farmers' fields in each landscape position were considered as random variables. Where significant differences were detected between means, standard error of differences (SED) values were calculated and used to compare means. In all figures in this paper, error bars represent standard errors of the differences (SED) of means.

6.3 Results

6.3.1 Maize and legumes grain yields during the first season
Differences in mean maize yields across locations and landscape were significant (Figure 6.2a). In Rugeramigozi, maize yield from the footslope plots was higher compared to other landscape positions whilst the best maize yield in Cyabayaga was obtained on the wetland. Application of FYM and DAP resulted in greater maize yields across the sites and landscape positions (Figure 6.2b). Legume grain yields were generally lower in Rugeramigozi compared to Cyabayaga with limited differences between landscape positions (Fig. 6.3a). Soybean yields were significantly higher than bean yields on the hillside plots in Cyabayaga while the reverse was true for the hillside plots in Rugeramigozi (Figure 6.3a). Beans generally responded to application of FYM and DAP but less so for soybean (Figure 6.3b). Fertilizer application increased grain yield of beans and soybean at both sites (Figure 6.3c).

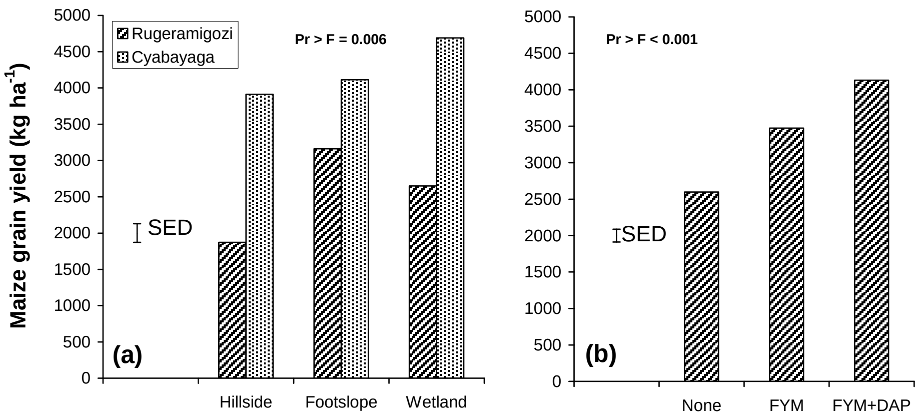


Figure6.2. (a) First season maize grain yields from the hillside, footslope and wetland positions in Rugeramigozi and Cyabayaga and (b) first season maize grain yields for different types of inputs applied. 'SED' refers to standard error of the difference for the respective factor or interaction presented. The significance of the factors or interactions is also indicated.

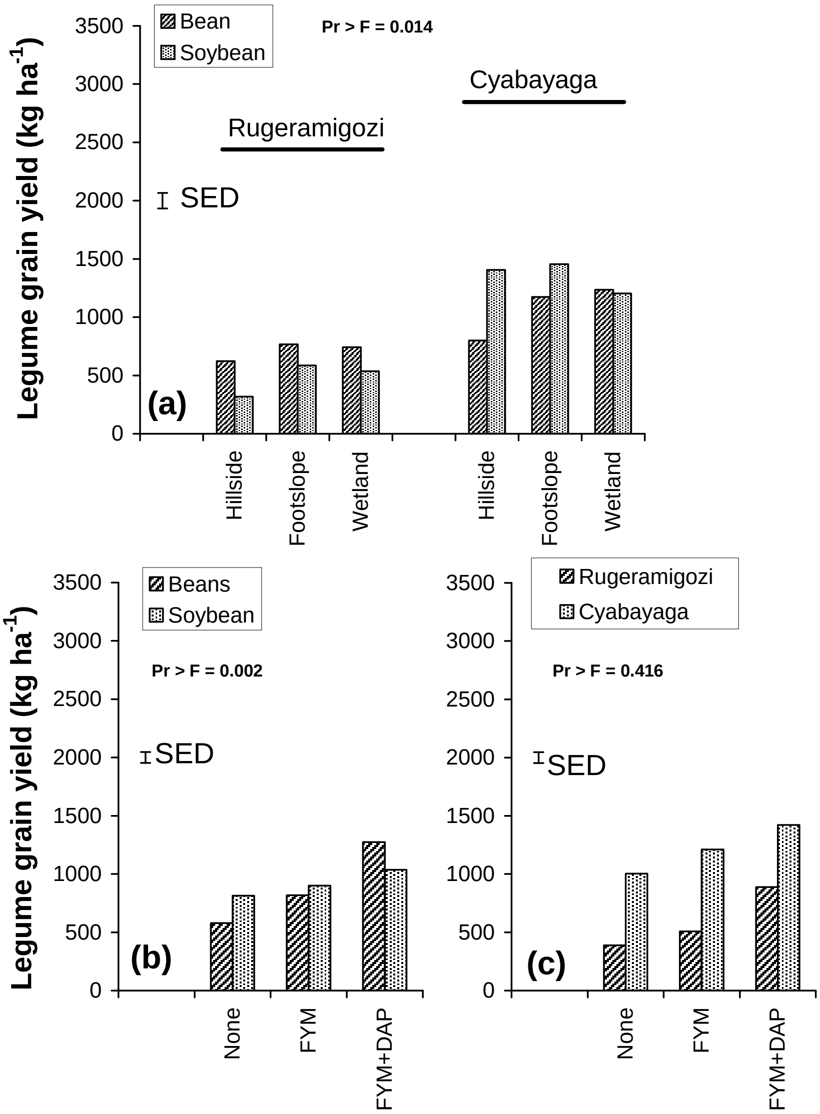


Figure 6.3. Legume grain yields from the hillside, footslope and wetland trials in Rugeramigozi and Cyabayaga (a), legume yields as affected by inputs application (b), and legumes yields for different types of inputs in Rugeramigozi and Cyabayaga (c). 'SED' refers to standard error of the difference for the respective interactions presented. The significance of the interactions is also indicated.

6.3.2 Legume aboveground biomass production

Legumes aboveground biomass accumulation was significantly higher in Cyabayaga than in Rugeramigozi with soybean producing more biomass in most landscape positions (Figure 6.4a). Both bean and soybean crops responded significantly to the application of FYM and FYM + DAP (Figure 6.4b). Responses to application of inputs were higher in Cyabayaga than in Rugeramigozi with insignificant effects of FYM application to in the latter site (Figure 6.4c).

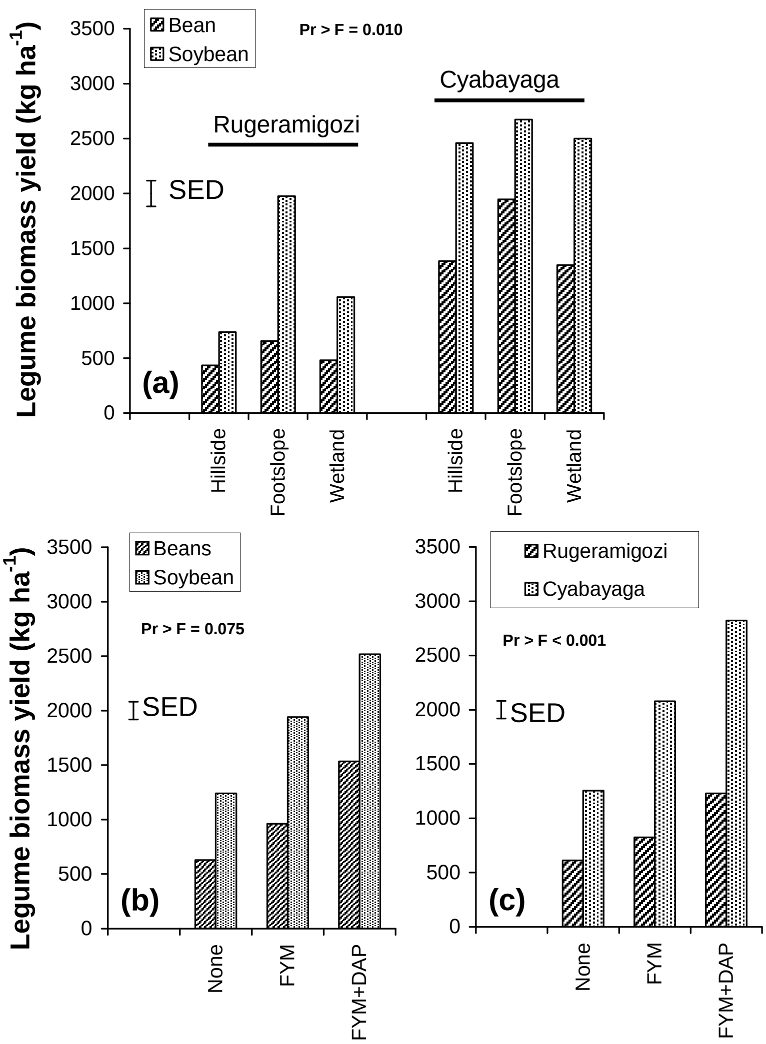


Figure 6.4. Legume biomass production from the hillside, footslope and wetland trials in Rugeramigozi and Cyabayaga (a), legume biomass production as affected by inputs application (b), and legumes biomass production for different types of inputs in Rugeramigozi and Cyabayaga (c). 'SED' refers to standard error of the difference for the respective interactions presented. The significance of the interactions is also indicated.

6.3.3 N uptake and N-fixation

Total legume aboveground biomass uptake was highest on the footslope fields, higher of soybean than for beans, and significantly higher after application of FYM+DAP for both sites, although the interaction with site was only significant for the latter (Figures 6.5a, 6.5b, 6.5c). Proportions derived from N fixation were significantly higher in the wetlands in Rugeramigozi compared to Cyabayaga (Fig. 6.5d). Soybean fixed significantly larger proportions of N than beans in Rugeramigozi while the inverse was true for Cyabayaga (Figure 6.5e). Application of FYM and DAP significantly increase the proportion of N fixed at both sites (Figure 6.5f). The total amount of N fixed was significantly higher in Rugeramigozi than in Cyabayaga (Figure 6.5g). While soybean fixed more N than beans in Rugeramigozi, amounts of N fixed were similar in Cyabayaga (Figure 6.5h). Application of FYM and DAP significantly increase the proportion of N fixed at both sites (Figure 6.5i).

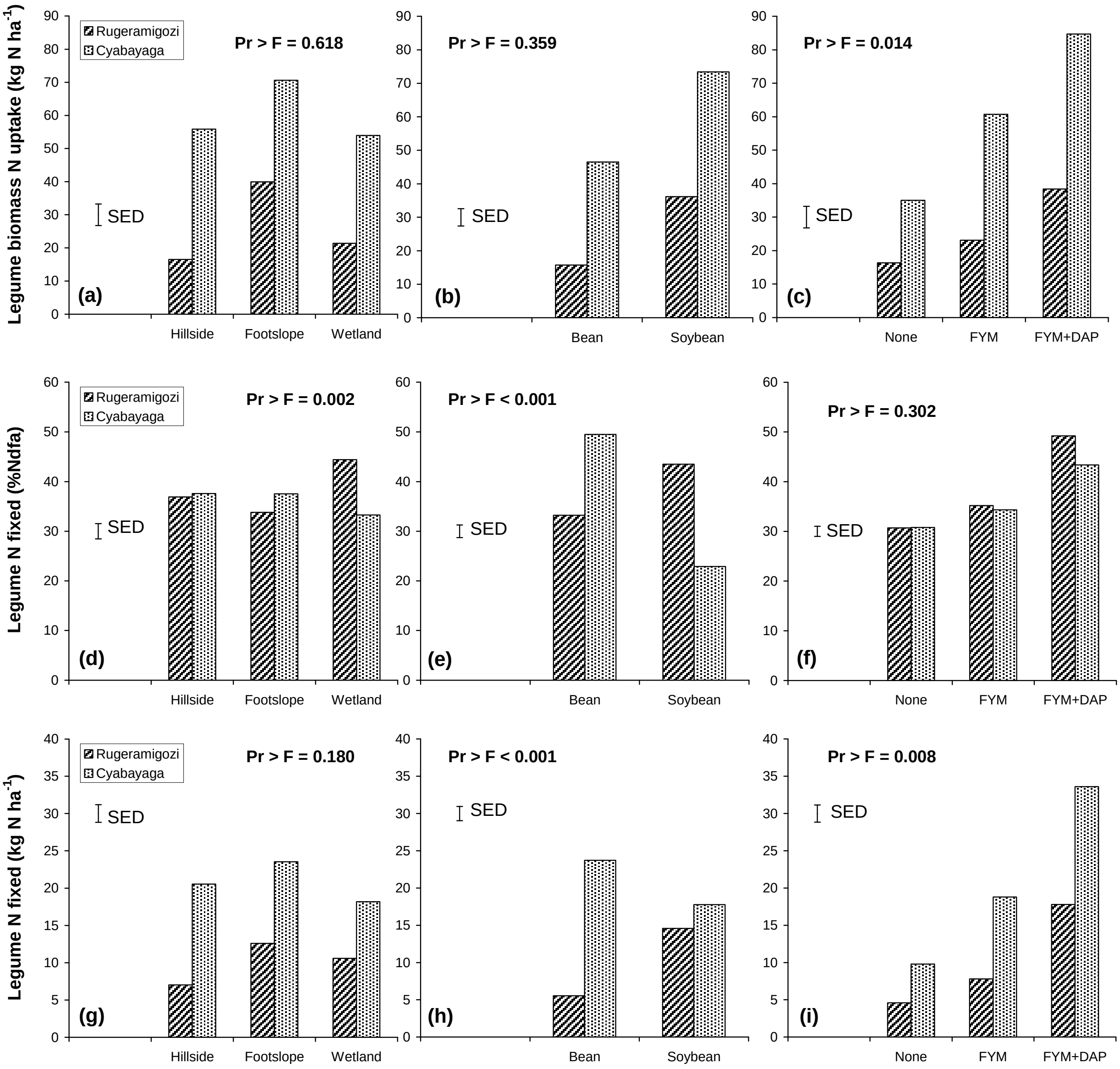


Figure 6.5. Aboveground biomass N uptake from the different landscape positions (a), for the different crops (b), and for the different inputs at both sites (c), the proportion of N fixed from the different landscape positions (d), for the different crops (e), and for the different inputs at both sites (f), and the total amount of N fixed from the different landscape positions (g), for the different crops (h), and for the different inputs at both sites (i). 'SED' refers to standard error of the difference for the respective interactions presented. The significance of the interactions is also indicated.

6.3.4. Export of N through legume grains and N balance

Export of N through legume grain harvest was significantly higher for soybean than beans in Cyabayaga but not in Rugeramigozi (Figure 6.6a). In Cyabayaga, bean grain N export was higher in the wetland than in the hillside plots while for soybean, an inverse trend was found. Differences in grain N export between landscape positions were minimal in Rugeramigozi (Figure 6.6a). Application of DAP and FYM resulted in significantly higher grain N exports than the no-input control for both legumes (Figure 6.6b).

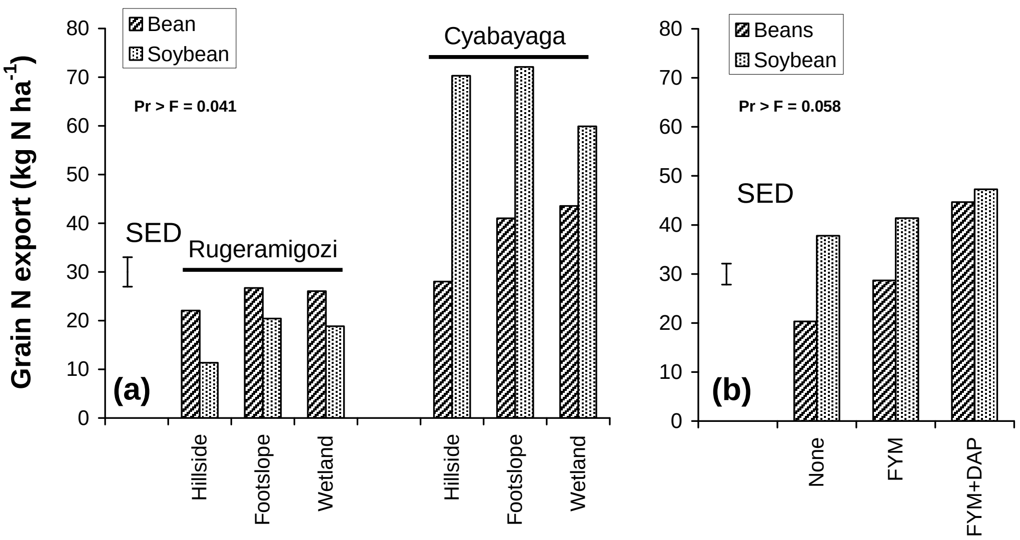


Figure 6.6. Exported N through legume grain harvest for beans and soybean from the different landscape positions at both sites (a) and for the different input applications for both crops (b). 'SED' refers to standard error of the difference for the respective interactions presented. The significance of the interactions is also indicated.

N balances were significantly lower for soybean than beans in Cyabayaga and the reverse was found in Rugeramigozi (Fig. 6.7a). In Cyabayaga, the bean N balance was more negative in the wetlands than in the other plots while the soybean N balance was least negative in the wetlands. Differences in N balances between landscape positions were minimal in Rugeramigozi (Fig. 6.7a). Application of DAP and FYM resulted in significantly lower N balances for soybean while the reverse was found for beans (Fig. 6.7b).

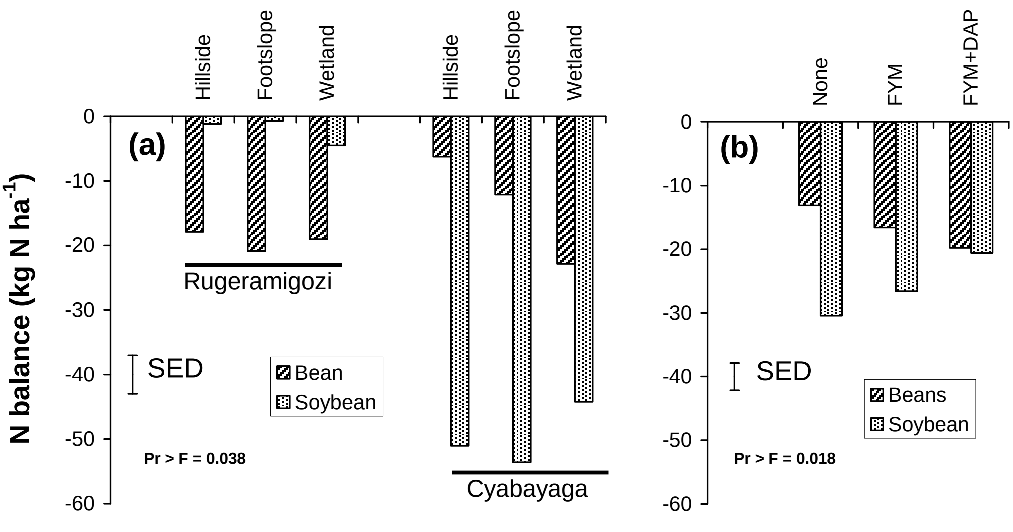


Figure 6.7. N balance for beans and soybean from the different landscape positions at both sites (a) and for the different input applications for both crops (b). 'SED' refers to standard error of the difference for the respective interactions presented. The significance of the interactions is also indicated.

6.3.4 Residual effects

Maize grain yields during the second season were significantly lower in the hillside than in the wetland plots for both sites (Figure 6.8a). Application of FYM and FYM + DAP resulted in significantly higher maize grain yields (Figure 6.8b), while yields after beans or soybean were also significantly higher than after maize (Figure 6.8c).

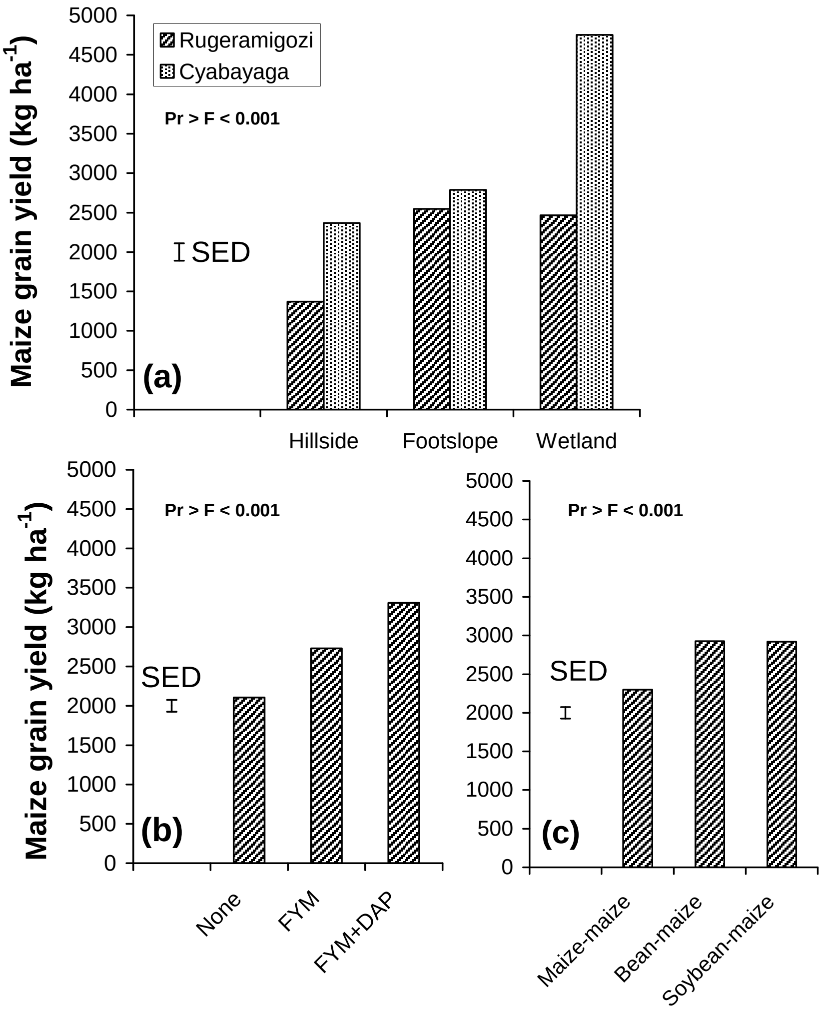


Figure 6.8.Second season maize grain yields for the different landscape positions at both sites (a), as affected by input application (b), and as affected by the previous crop (c). 'SED' refers to standard error of the difference for the respective factors or interactions presented. The significance of the factors or interactions is also indicated.

6.4 Discussion

The productivity and N fixation of the tested legumes and subsequent maize cultivation varied greatly between sites, with different fertilizer and in the different landscape positions. Higher fertility status in Cyabayaga can explain higher yields in Cyabayaga in both grain and biomass shoot production.Furthermore, the promiscious soybean used in this study was screened in Nyagagatre where the site of Cyabayaga belongsto, hence greater adaptation can be expected compared to Rugeramigozi. The grain yields of the promiscious soybean in Cyabayaga was comparable to those reported for promiscious soybean species grown without inoculation in savannah (Oikeh et al., 2010). However, the total N accumulation reported by Oikeh et al. (2010) was more than twofold the values obtained in the present study.

Generally, differences in soil fertility between landscape positions were smaller in Rugeramigozi than in Cyabayaga. This observation could be related to soil management.According to Nabahungu et al. (2011), farmers of Cyabayaga use both organic and inorganic input on rice crop in wetlands,which is an important cash crop. In Rugeramigozi similar crops are grown in both wetland and on hillside andthe soil fertility management tends to be the same (Nabahungu et al., 2011a, ch 3). Higher productivity of shoot dry matter and legume and grains, fixed N and subsequent maize grain were recorded in both wetland and footslope. This trend may be due to low soil moisture content and low soil fertility in Cyabayaga on hillside.The significant reduction in N-fixation and productivity of both legumes and cereals in the hillside suggests that the productivity and N benefit of legumes are likely to be small in systems characterized by low water content and poor soil fertility. Therefore, different technologies of ISFM are needed for the improvement of productivity on smallholder farms in different agro-ecological zones and landscape positions in Rwanda. According to Peoples et al. (2009), a number of biotic and abiotic factors affect N-fixation. Symbiotic N-fixation is highly sensitive to water stress (Serraj et al., 1999; Devries et al., 1989). Similarly, Sinclair et al. (1987) observed that N-fixation in soybean was sensitive to low moisture content in soil, a situation which underscores the shortcomings of N-fixation in the drylands.

Application of FYM in combination of DAP was essential for N-fixation by legumes and N uptake, good legume and maize production and has a positive residual effect on cereal yield at both sites. This confirms the importance of P in increasing N fixation and production of legumes (Kihara et al., 2010). P deficiency was found to be a major factor limiting symbiotic N_2-fixation (Zaman-Allah et al., 2007). Kiharaet al. (2010) also reported that the use of P during the legume phase not only increased the productivity of the legume crop but also led to significant residual effects on the succeeding cereal crop. Fertilizer application has been shown to increase the efficiency of legumes to fix N (Peoples et al., 2009), enhance nodulation and nodule functioning, aboveground biomass and total N in legumes residues (Besmer et al., 2003). Furthermore, soil nitrate and N-fixation are complementary in meeting the N requirements for growth by a legume crop. However, high concentration of soil nitrate has been shown experimentally to reduce both %NDFA and the amount of N fixed (Salvagiotti et al., 2008). There were no interactions between input use and landscape position, indicating that the same trends apply to all positions. The latter is a bit strange since one would expect limited responses in Cyabayaga in the wetlands and footslopes due to high fertility status. Further studies are needed to explain this.

The studied soybean and bean varieties were capable of fixing atmospheric N_2 on farms without artificial innoculation. However, the quantity of fixed N was very low (<30 kg ha^{-1}) compared to the quantities quoted in litterature (>60 kg ha^{-1})(Peoples et al., 2009). Although bush bean is cropped intensively in Rwanda it is known to fix only about 10kg N shoot N t DM^{-1} (Peoples et al., 2009). According to Peoples et al. (2009), the symbiosis is established when indigenous rhizobia infect the roots of legumes to produce nodules. Nonetheless, there are also soils where the strains are present but unsuitable for the legume that the farmer intends to grow. Moreover, even in soils with effective resident rhizobia, the populations may be too small to guarantee prompt formation of root nodules and, as consequence, optimal N-fixation (Herridge et al., 2005). Generally, the particular legume species most recently grown is a major determinant of the type and size of rhizobial populations in the soil (Thies et al., 1995). Despite the principle of rhizobial ecology that is useful populations of rhizobia remain in the soil when the same or a symbiotically related legume has been of the immediate past history of the land.

Although higher biomass production was recorded with the promiscious soybean compared to bean in Cyabayaga, the quantity of N fixed by soybean was very low compared to bush bean in the same siteleading to more negative N balances. Also, the soybean appears to be less promiscouos than the bean and actually exctracts more N from the soil in Cyabayaga. These results suggest that promiscuous soybean cultivars are not effectively nodulated by indigenous rhizobial populations in Cyabayaga. The lack of the biological N fixation observed for promiscuous soybean is probably due to the lack of appropriate strains. According to Mpepereki et al. (2000), different lines of promiscuous soybean varieties growing on the same soil vary considerably in their ability to fix N. The results are in accordance with findings by Sangiga et al. (2000) who noted that promiscuous soybean cultivars are incapable of nodulating effectively with indigenous rhizobia in all locations in the moist savannah zone of Nigeria. Similarly, Bala (2008) observed that it is not clear whether promiscuous soybean cultivars are effectively nodulated by indigenous rhizobial populations in all soils and under all conditions.

Although, the N-balance was negative in all sites and landscape positions under different organic and inorganic fertilizer applications, maize yield after legume was higher than under continous maize production for the two seasons studied. Also, while bean produces less biomass and accumulates less N, the rotational effects to maize are similar to those of soybean. These results imply that cereal yield responses after legume are not always fully attributed to improvements in soil N supply through nitrogen fixation. Maize yield improvement could also have been partly related to a number of factors including the soil organic matter pool (Schwenke et al., 2002), soil P by the secretion of organic acids such as citrate and malate (and other compounds)from their roots (Hocking, 2001).

Since below-ground contributions of fixed N have often was not estimated in this study, there is reason to believe that the total N fixed could have been underestimated. N fixed by below ground part including nodules and roots may represent between 30% and 60% of the total N accumulated by legume crops (e.g. Khan et al., 2003; Mahieu et al., 2007; McNeill and Fillery, 2008) according to (Peoples et al. (2009). As shown by Ojeim et al. (2007), the use of maize species as a non-N2-fixing reference species in ^{15}N natural abundance method could have underestimated the percentage of NDFA.

6.5 Conclusion

Productivity and N-fixation of the legumes and subsequent maize cultivation varied greatly between sites and different fertilizers and in different landscape positions. Therefore, we suggest that different technologies of ISFM are needed for the improvement of productivity of smallholder farms in specific agro-ecological zones and landscape positions in Rwanda. Since the potential of legume species varies in the different agro-ecological zones andlandscape positions, careful selection is needed to optimize productivity and N- fixation.

Although, the N-balance was negative in all sites and landscape positions and under all tested fertilizer applications, maize yield after legume was higher than continous maize production for the two seasons studied. The results indicated that cereal yield responses after legume cannot be attributed only to improvements in soil N from nitrogen fixation. In this respect, it is important to mention that our estimate of N fixed was done on shoot dry matter basis and this method may have underestimated the levels of N fixed in legumes. Estimating the total N fixed including root part would have been the most appropriate method but, such an assessment isdifficult due to the complications associated with the recovery of complete root systems.

Although higher biomass production was recorded with the promiscious soybean in Cyabayaga, the quantity of N fixed by soybean was very low in both sites. This suggests that promiscuous soybean cultivars were not effectively nodulated by indigenous rhizobial populations. We conclude that rather than screenning legumes for the ability to nodulate with indigenous strains of unknown potential, it will be safer to rely on well known inoculants strains to ensure satisfactory and effective nodulation. The fact that imported promiscuous soybean poorly fixes N suggest that breeding programs for enhancing N-fixation in soybeanshoulddiversify the pool of both local and imported strain species to ensure tangible results.

Chapter 7

Synthesis

Synthesis

Wetlands are critical for numerous functions in hydrological, chemical and biological ecosystem cycles and have great agricultural potential when properly used. Wetlands are multi-functional natural reservoirs; and on whose productivity and hydrological benefits, whole communities can depend upon. These wetland benefits are particularly important in the dry parts of developing countries where the strategic importance of wetlands for rural livelihoods can be enormous (Scoones, 1991; Silvius et al., 2000). This is also true, to a lesser but growing extent, in wetter highland areas, e.g. in Rwanda, where land shortage is a continuously growing problem due to persistent increase in population pressure (Dixon, 2002, Nabahungu and Visser, 2011b). However, increasing the use of wetlands for agriculture reduces their natural status and the range of ecosystem services they can provide (McCartney and Houghton-Carr, 2009). A balance must be obtained between the direct market-based economic gains achieved through intensive agricultural activities on reclaimed wetlands, and the corresponding risks to non-market, social and environmental benefits from natural ecosystems. Therefore the focus of this thesis was the understanding of key problems and opportunities in the management of wetlands for long term productivity in Rwanda.

The central problem with wetland use in Rwanda as identified in the introduction of this thesis is the lack of an integrated approach for wetland development. It was hypothesized that *an integrated watershed management (IWM) approach which includes farmers' knowledge of problems and opportunities; as well as their experience about wetland uses, is key to development of strategies for sustainable wetland management in Rwanda*. Therefore, the aim of this research was to improve the level of understanding of the current use of wetlands by smallholders: their problems and opportunities. Essential in IWM is the understanding of its multi-dimensional character, their levels of stratifications (household, watershed, and national); and the full use of farmers' knowledge and participation. Therefore, besides extensive farm level surveys that were conducted, attention was also paid to functions, problems and opportunities at the national scale.

The Cyabayaga and Rugeramigozi wetlands were selected for study because they represented two important aspects of typical wetland agriculture in Rwanda. Rugeramigozi lies in the highly populated central plateau zone of Rwanda where pressure on land is high. In Cyabayaga, land pressure is lower and soil fertility is higher than in Rugeramigozi. A novel combination of multidisciplinary research methodologies, applied at different scales, was used in these watersheds to address the research questions and test our hypothesis.

This thesis identified and verified important information regarding problems and opportunities related to wetland management in Rwanda. The results indicate that there is potential in Rwanda for integrating scientific and local knowledge at multiple levels to form IWM plans which balance the apparently conflicting stakeholder interests in increased productivity and long-term protection of wetland areas. If there is the political will to implement these plans through policy and investment from the national to local farmer level, will greatly and sustainably benefit the people and environment of Rwanda.

7.1 Answers to the research questions

7.1.1 The role of wetlands in the current smallholder farming system

Most Rwandan farmers practice subsistence farming. Existing data show that farmers living in the uplands make use of the neighbouring wetlands and generally plant similar crops in both up- and lowlands, except for paddy farming which is cultivated exclusively in wetlands (Ngarambe and Kanyarukiga, 1998). The effect of fertilizer use and biological N-fixation on crop productivity varies between the different econiches (wetland, foothill and hillside), both within the (watershed) and between the Rugeramigozi and Cyabayaga wetlands, where different fertilizer regimes are used. Productivity and N-fixation of legumes in rotation with maize varied greatly between the different econiches. Higher productivity of shoot dry matter, legume grain, and subsequent maize grain due fixed N, were recorded in both wetland and foothill compared to the hillside plots. Our research confirms that the variability in soil parameters from hilltops to wetlands in Rwanda has a significantly impact on crop productivity; with wetlands regularly registering higher yields than hillsides. This has implications for the farming systems, in terms of types of technologies and ISFM approaches needed to improve the productivity of smallholder farms in different agro-ecological zones and eco-niches in Rwanda.

Results from this study show that agricultural potential, cropping system (choice of crops), access to resources, gross margin, size of livestock herd and farmers resource endowment influence the magnitude of nutrient fluxes. They confirm findings in other African countries that farmers' decisions on soil fertility management are influenced by both the socio-economic and the biophysical environment, resource endowment and production objectives (Tittonell et al., 2005; Haileslassie et al., 2007). The thesis also verified that the value and marketability of crops produced are critical factors influencing farmers' decisions to invest in soil fertility improvement. In contrast to many studies which have identified fields closer to the homesteads as zones of nutrient accumulation and distant fields as zone of nutrient depletion (Vanlauwe and Giller, 2006; Vanlauwe et al., 2006), this study reveals that farmers may not necessarily be concentrating nutrients around their homestead because of the short distance. Rather, farmers apply nutrients in plots which they perceive to be fertile and reliable for production because of satisfactory yields. Thus, the amount of resources used at the farm level is closely linked to the expected increase in productivity gain.

The results from the two contrasting wetlands verify that the primary benefits from wetlands for farmers vary with wetland types. While income generation is the primary benefit n Cyabayaga, in Rugeramigozi, food security is the greatest benefit. Rice is an important crop in both wetlands. However, farmers cultivate rice because it is a government policy, especially in Rugeramigozi wetland. Adoption of rice as the main crop for the wetlands for income generation could be higher when varieties adapted to local circumstances become available. These findings are consistent with the results from other studies in wetlands in Rwanda (Mbarushima and Nsabimana, 2008, Kayiranga, 2006).

As with the primary benefits, the dependency of households on wetlands also varies between sites. The results of our research has proven that field size, status of soil fertility and input use, are key factors determining the magnitude of the contribution of wetland agriculture to farmers' livelihood in Rwanda. In Cyabayaga, the per household per year contribution of wetland cultivation to gross margin (GM) was 74% ($ 1901 U.S.) compared to just 24% ($ 84 U.S.) in Rugeramigozi. These results confirm findings from studies in other countries which showed a wide range in the contribution of wetland cultivation to household income in Africa often due to natural setting, the socio-economic situation of the community and household, and the, political history of the national economies (Emerton et al., 1999; Morardet and Tchamba, 2005; Adekola et al., 2008; Rebelo et al., 2009). Rice in Cyabayaga was the largest contributor to household income providing on average $ 1045 per household per season. In Rugeramigozi, vegetables cultivated in the dry season have high potential as cash crops. These differences show the importance of broadening the geographical coverage and scope of research, policy and investment priorities.

Notably this thesis highlights the importance of linking hillsides and wetlands in analysing farm household systems in Rwanda. It shows that a strong linkage between farming in wetlands and hillsides is required to support the livelihood of farmers; supports the conclusion of Willetts (2008) that linking hillside and wetland agriculture in Rugezi is a plausible tool for climate change adaptation and energy sector resilience in Rwanda. This thesis identifies the integration of livestock and agriculture when designing new technologies as a desirable strategy for attaining sustainable integration of hillside and wetland management.

7.1.2 Problems farmers face in wetland use

Degradation of the wetlands is not only a direct threat to food and income security of small scale farmers in Rwanda. A previous case study of Rugezi wetland explains how degradation has resulted in falling water levels, which in turn developed into an energy crisis with grievous social impacts (REMA, 2009). There is also evidence that indiscriminate reclamation (destruction) of wetlands, with no consideration for their ecological functions, may result in irreversible damage to wetland ecosystems (Morardet and Tchamba, 2005). Rwanda's location, at the heart of a dense hydrological network that constitute the headwaters of the Nile and Congo rivers, means that the impacts of wetland degradation in Rwanda are likely to extend to surrounding and downstream lands and peoples beyond Rwanda.

The greatest threats to agricultural wetlands and causes of poor wetland management are associated with soil suitability, land ownership, water management and weak farmer organizations (Chapter 3). Results of our research identify inappropriate cropping systems in wetlands; lack of availability of improved seeds and high prices of fertilizers as the major famers' constraints in wetland use. Despite the synergy advocated in crop-livestock integration, our research found that the nutrient cycling of crops to animals and animal manure to crops has the potential to render the system unsustainable without added external inputs.

Soil suitability was verified to be related to many parameters which cause yield variability, particularly water availability and infiltration rate. In spite of the apparent continuous availability of (ground) water, a major constraint identified by farmers in the two wetlands was water shortage. These results confirm the findings of previous research in Tanzania (Mwakalila, 2006) and in Rwanda (Kayiranga, 2006), which assert that availability of water depends on the location of the field and soil type in wetlands. In fact, water shortage is one of the most common complaints in both wetlands studied, and questions the relevance of rice as the preferred, and policy recommended, cash crop in the context of its high water demand. Therefore, another main issue among farmers is the lack of compromise between crop rotation and rice mono-cropping to improve water use efficiency

The study research revealed that a major source of the problem was poor maintenance of drainage and irrigation channels. Farmers recognized that the essential maintenance of common pool resources, such as the central drainage and irrigation channel, is also a major cause of conflicts among farmers. Ignoring of proper maintenance advisories of drainage and irrigation channels in wetland systems inevitably affect adjacent wetlands plots in terms of flooding or water availability.

To address the issues and solve water management conflicts, farmer-led cooperatives are formed in reclaimed wetlands. However, farmers doubt the ability of the cooperative committees to maintain equitably shared use of wetland for sustainable production. This was attributed to authoritative styles of management where decisions are often taken without member participation or consultation. Members also feel powerless to change cooperative committee management. Although farmer led cooperatives can provide numerous benefits to members (Ortmann and King, 2007), according to Akwabi-Ameyaw (1997) these cooperatives have often not been successful in Africa because of problems in holding management accountable to the members, leading to financial irregularities in management.

7.1.3 Opportunities for improved wetland use

In 2005 the government of Rwanda adopted measures to prevent all human activities in the Rugezi wetland. Rugezi wetland was registered as Ramsar site in 2006 (REMA, 2009) and is now fully protected. This proves that opportunities exist for improved wetland use and management. These opportunities hold potential for achieving the needed balance between intensified use and protection of the eco-system services the wetlands provide – as the result of successfully fighting degradation.

One of the biggest opportunities for improving the use and management of wetlands in Rwanda is to include farmers, and their knowledge and terminology, in the discussions and decision making process.

Farmers have knowledge on the causes and the potential solutions to overcome many of the constraints related to agricultural management. They know that soil suitability is closely related to relief and improved resource use. In the two agro-ecological zones we studied, situated in different provinces, farmers used the same names for their soils. This is a strong indication that there is consistency in knowledge and terminology across the country. The farmers' soil knowledge in the watersheds we studied is also in agreement with findings reported by Habarurema and Steiner (1997) and Steiner (1998) on other farmers in Rwanda, who associated soil suitability with slope position. They classify soils by a number of criteria and choose crops accordingly. Therefore, using farmers' terms for soil suitability will improve communication and mutual understanding among stakeholders involved in agricultural wetlands. From the findings of this project, the author strongly agrees with Martin and Sherington (1997) that there is much to be learnt from the interaction between farmers' research and formal research, because such participatory research draws on both indigenous and scientific knowledge systems. Any programme designed to address wetland management in Rwanda will have a much better chance of success if farmers and their knowledge are included in a holistic package of wetland management.

The results of this project's multi-locational trial conducted at two sites (Rugeramigozi in Southern Rwanda, Cyabayaga in Eastern Rwanda) on three landscape positions (valley bottoms, footslopes and hillsides) clearly demonstrated that increased use of appropriate Integrated soil fertility management (ISFM) practices is a significant opportunity for improving watershed productivity. The results showed that use of a nitrogen-fixing grain legume, farmyard manure (FYM) and limited amounts of additional fertilizer can enhance grain legume and maize productivity. Vanlauwe et al. (2001) found similar results in some parts of West Africa which indicated that organic matter management and fertilizer combined, but neither one alone, has the potential to solve farmers' soil fertility problems. Both findings therefore confirm that sustainable improvements in crop yields, soil fertility, and gross margins can be attained by using a combination of external inputs, improved technologies and integration of wetlands with hillsides agriculture. However, this is often limited due to costs and the risks (real or perceived) associated with investing in and growing certain high-value crops. Reducing these costs and risks provides an opportunity for increasing wetland productivity. This can be realized in a number of ways including introduction of crop varieties which are proven to be adapted to local wetland conditions because of high yields, resistance or tolerance to diseases, and responsiveness to proven ISFM practices. In addition, various economic initiatives and incentives also offer possibilities for progress in this area. These include: initiatives that increase market opportunities can broaden the horizon and scope where farmers are willing to make investment; incentives can reduce risk by facilitating investment, reducing total cost, or simply providing assurance of a guaranteed return. Our findings agree with the views of Yanggen et al. (1998), who conclude that reducing risks and uncertainty in input markets, local access to affordable packages at the right times, fertilizer promotion in areas with functioning output markets, and demonstrations of soil management all serve to improve adoption of new, production boosting technologies.

7.2 The research hypothesis

The research hypothesis was that an integrated watershed management approach which includes farmers' knowledge and experience about wetland uses, problems and opportunities is key to development of strategies for sustainable wetland management in Rwanda. The main characteristics of IWM are that it is multi-functional, multi-level and participatory. Our analysis shows that wetlands are multi-functional ecosystems and that effective decision-making must balance wetlands conservation and the contribution of natural wetlands to farmers' livelihood. This can only be achieved with proper stakeholder involvement from different levels; from the national to the farmers' level.

Promising strategies for improved wetland management exist. Examples from this thesis include involvement of the full range of wetlands stakeholders in issue evaluation and strategy development

(Chapter 2); collaboration between scientists, engineers, farmers and extension regarding terminology and development of sustainable cropping programs and recommendations (Chapter 3); introduction of crop varieties more suited to the wetland conditions (Chapter 4); locally adapted policy development and economic incentives to reduce farmer risk and support investment (Chapter 5); and more site specific selection of crops and fertilizer types and programs (Chapter 6).

These elements of an integrated watershed approach were examined during the research process for their potential to contribute to sustainable rehabilitation and management of wetlands in Rwanda. Therefore the research hypothesis of this thesis is supported. Application of such an approach and its subsequent implementation will be the real proof of the pudding, however that is more of a development issue and was not the aim (and is beyond the reach) of our research.

7.3 Generated knowledge

This thesis reveals the extent to which degradation of wetlands negatively affects individuals, households, communities, the national economy and even potentially the greater hydrology of a region. The Rugezi case study is a classical example of how degradation of wetland ecosystems can have multiple consequences; that is the linkages between insufficient supply of electricity in Rwanda and the adverse impact on the economy to wetland degradation. Likewise our results indicate that improved methods of sustainable use of natural resources, has multiplier effects to several other sectors of the economy and GDP as a whole.

Clear differences in nutrient balances and gross margins between the two wetlands studied were demonstrated. The poor, subsistence oriented production systems in the Rugeramigozi wetland is related to the small field sizes both in the wetland and on the hillside, and low input use. Lower inherent soil fertility, shortage of land and the lack of well-adapted high value crops explains the deepening spiral of low productivity/ low investments/ and increased soil degradation in Rugeramigozi, both in wetlands and on the hillside. Farmers do not have the resources to break this cycle without economic and policy assistance. Discovery and verification of these differences implies that no blanket recommendations can be made and that site specific approaches are needed.

Those who derive their livelihood directly from wetlands are well aware of the value of the water supply in terms of craft material and dry season crop harvests/pastures provided by wetlands. While this idea has also been researched in other places, this thesis has proven that local knowledge in Rwanda is also vast and applicable to development of future management programs; and provided key information needed for developing successful wetland management strategies. Furthermore, and in contrast to many studies that identify homestead fields as zones of nutrient accumulation, and distant fields (like the wetland plots) as zones of nutrient depletion, our research found that, in Rwanda, more labour and nutrient resources are allocated to and used in wetland fields (as compared with upland fields) to maximize production for sale and profit. Farmers in Rwanda apply nutrients in wetlands because the wetland is perceived to be fertile and has a high likelihood of producing satisfactory yields. Thus, the amount of resources used at the farm level is closely tied to the expected potential increase in productivity from the extra investment. As reviewed in Chapter 5, the value and marketability of the crops produced are critical factors in the decision to invest in soil fertility improvement and as such of vital importance in the development of successful wetland management strategies.

The application of an appropriate integrated soil fertility management practice in a specific eco-niche provides a large potential to increase soil productivity. Although higher biomass production was recorded with the high yielding soybean compared to bush bean in Cyabayaga, the quantity of N fixed by soybean was low compared to that of bush bean at the same site. This suggests that high producing soybean cultivars are not effectively nodulated by indigenous rhizobial populations. This observation suggests that it is more reliable to use effectively proven inoculant strains rather than trying to breed for the ability to nodulate within indigenous strains of unknown potential. Given that the potential of species varies in the different biophysical niches and agro-ecological zones, careful crop selection and more condition specific types and rates of fertilizer are needed to optimize productivity. The soybean and bean varieties studied were capable of fixing atmospheric N_2 on farms without artificial innoculation, however the quantity of fixed N was much lower (<30 kg ha^{-1}) than quantities quoted in literature (>60 kg ha^{-1}).

Maize yield after legumes was higher than continous maize production for the two seasons studied. The N balance was negative in both sites at all topographic sites and under all fertilizer applications. This proves that maize yield response after legumes is not only attributable to improvements in soil N supply through N fixation but that there are residual and indirect effects. The measured effect may be due to the contribution of legume residues to the soil organic matter pool; thereby providing potential for enhanced N mineralization and leading to an increased concentration of soil mineral N. Furthermore, legumes are known to be able to mobilize fixed forms of soil P by the secretion of organic acids such as citrate and malate (and other compounds) from their roots.

7.4 Research recommendations

The complexity of wetland management as identified in this study emphasizes the need for a critical analysis of biophysical, social and economic factors that underpin the dynamics of wetland resource use prior to its large-scale reclamation. Lack of data and stakeholder interaction on which to base policy development and decision making leads to poor policy design, exacerbating user conflicts resulting in poor wetland management. The findings of this thesis make it clear that more interdisciplinary research, both in policy and in technology, is needed to increase our knowledge base and its use by end-users of wetlands with the aim to improve their income and to make their livelihoods more sustainable. Though this research builds largely on farmers' knowledge of wetland management insufficient time was available to verify the (soft) knowledge gained from farmers with (hard) measurements.

As has been noted, the discovery of marked differences in wetlands in Rwanda means that no blanket specific recommendations can be made. This study was only being able to generate knowledge about the situation – and did not have the ability to put the ideas generated into action. However the Rugezi case showed that regeneration of degraded wetland is possible. More (detailed) studies of the resilience capacity of wetlands for different intensities and types of uses are needed. Different approaches that are effective in the different areas can be the focus of future research. Consequently methods for upscaling proposed mitigation measures to different users must be developed and/or tested.

To increase and sustain productivity, productivity enhancing technologies such as improved rice varieties and crop rotations with high yielding legumes and high capacity of N fixation should be tested in more locations to verify their local applicability and potential adoption.

7.5 Policy recommendations

Two of the biggest challenges facing Rwanda today are reducing poverty, especially among rural households, and protecting ecosystems, which provide essential services that support activities such as subsistence agriculture. Combining these two objectives is not easy and there are numerous pitfalls to effective policy design. Useful information for policy development and decision making with respect to the trade-offs among alternative management and use options of wetlands in Rwanda and possibly other similar areas of the world is provided. A delicate balance must be kept between use of the rich wetland resources for agriculture and ecosystem conservation. This is essential, to ensure sustainable wetlands use.

The information generated in this thesis makes important contributions to determining the focus needed in development of effective policy and investment decisions. Subsequently, these decisions guide on how to mitigate land degradation, to raise awareness and improved communication at ministry and at local stakeholders levels, and to empower farmers and build their capacity. Also, findings of this study stress the need of integrated watershed management for improved wetland management.

The processes that affect land management and land degradation in Rwandan wetlands are tied to economic, social and agricultural policies. Addressing land degradation will, therefore, require not only technical solutions but also improved socio-economic and institutional conditions. Programs to prevent and mitigate land degradation need to be implemented within a broad economic development plan taking into account both agricultural and non-agricultural interventions. Results in Chapter one sustain the need for joint planning of different ministries – environment, lands, economic planning and finance, agriculture and tourism – on the use and management of wetlands. Consequently, each ministry has its own view making effective use of the wetlands. The ministry of agriculture, for instance, considers wetlands as areas with little value, only productive when reclaimed for intensive agricultural use. Raising awareness should, therefore, primarily target policymakers in the agriculture and water resources sectors. So that the multiple benefits from wetlands and the multiple recipients of these benefits are considered in a holistic catchment-wide context.

Furthermore, most of the time, wetlands are destroyed by human development resulting from the strong financial incentives for development of the natural resource value of wetlands. Effective decision-making must balance wetlands conservation and the contribution of natural wetlands to farmers' livelihood. Community leaders and the members of wetland management committees need to recognize the full range of stakeholders who use these areas and involve them all in wetland decision making processes. This will ensure that wetland use is not just economically but also ecologically and socially sustainable.

This thesis has clearly shown that farmers are well aware of the problems and opportunities related to agriculture in wetlands. Therefore, for improved wetland management, engineers, scientists, extension specialists and policy makers need to not only make use of farmers' knowledge to empower farmers' cooperatives, but also to work more closely with them in order to identify and offer a range of proven crop and soil management recommendations. Such measures will help to create trust and assist farmers in optimizing the use of their wetlands.

Some segments of society, especially those who are poor and holding smallest farms both in wetlands and on hillsides, are disproportionately affected by soil degradation and find it difficult to address the problem as this requires investments beyond their capacity. Thus, this category of farmers requires particular policy attention. Therefore, a strong synergy between farming in wetlands and on the hillside is required to support farmers' livelihood.

Using an integrated watershed approach appears to be the best strategy for the management and rehabilitation of wetlands in Rwanda. Experience has demonstrated that initiatives aimed at wetland conservation and management are successful only when they are recognized as a long-term process that aims at building a strong knowledge base to inform both policy and practice. Capacity building for wetland management is part of successful wetland use and management.

7.6 A final word

This thesis has substantiated and generated information that was previously missing regarding the urgent need for wetlands in Rwanda to be recognized as a critical component for long-term livelihood *and* natural resource management strategies. The findings from this multidisciplinary research project clearly show why more attention must be given to the development and adoption of sustainable wetland use technologies and practices that meet the needs of local communities and, at the same time, protect the hydrological system from degradation. Integrated watershed management is an opportunity for more sustainable management of wetlands and a goal that this thesis strongly recommends. Increased communication between all stakeholders, informed by actual social and environmental data, holds great potential for making progress toward this goal in the present and achieving sustainable future benefits for both the people and ecosystem of Rwanda.

References

Achard, F., & Banoin, M. (2003). Fallows, forage production and nutrient transfers by livestock in Niger. *Nutrient Cycling in Agroecosystems, 65*(2), 183-189.

Acharya, G. (2000). Approaches to valuing the hidden hydrological services of wetland ecosystems. *Ecological Economics, 35*(1), 63-74.

Adams, W. M. (1993). Indigenous Use of Wetlands and Sustainable Development in West Africa. *The Geographical Journal, 159*(2), 209-218.

Adekola, O., Morardet, S., de Groot, R., & Grelot, F. (2008). *The economic and livelihood value of provisioning services of the Ga-Mampa wetland, South Africa.* Paper presented at the Proceedings of the13th IWRA World Water Congress, Montpellier, France.

Adesina, A. A. (1996). Factors affecting the adoption of fertilizers by rice farmers in Côte d'Ivoire. *Nutrient Cycling in Agroecosystems, 46*(1), 29-39.

Adger, W. N., & Luttrell, C. (2000). Property rights and the utilization of wetlands. *Ecological Economics, 35*(1), 75-89.

Agrawal, A. (1995). *Dismantling the Divide Between Indigenous and Scientific Knowledge* (Vol. 26): Development and Change.

Akwabi-Ameyaw, K. (1997). Producer cooperative resettlement projects in Zimbabwe: Lessons from a failed agricultural development strategy. *World Development, 25*(3), 437-456.

Andrew, G., & Masozera, M. (2010). Payment for ecosystem services and poverty reduction in Rwanda. *Journal of sustainable development in Africa, 12*(3), 122-139.

Ansoms, A., & McKay, A. (2010). A quantitative analysis of poverty and livelihood profiles: The case of rural Rwanda. *Food Policy, 35*(6), 584-598.

Baijukya, F. P., de Ridder, N., 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. *Agriculture, Ecosystems & Environment, 106*(4), 395-406.

Bala, A. (2008, 17-21 March). *Recent advances in soybean inoculums research and applications: Towards enhancing productivity in smallholder agriculture.* Paper presented at the Paper presented at an International Workshop on Rhizobium Inoculation, Impala Hotel, Arusha Tanzania.

Balasubramanian, V., & Egli, A. (1986). The role of agroforestry in the farming systems in Rwanda with special reference to the Bugesera-Gisaka-Migongo (BGM) region. *Agroforestry Systems, 4*(4), 271-289.

Barbier, E. B. (1996). Valuing Environmental Functions: Tropical Wetlands. *Land Economics, 70*, 155-173.

Barbier, E. B., Acreman, M., Knoweler, D. (1997). *Economic valuation of wetlands: A guide for policy makers and planners*: Ramsar Convention Bureau, Gland Switzerland.

Bationo, A., Lompo, F., & Koala, S. (1998). Research on nutrient flows and balances in west Africa: state-of-the-art. *Agriculture, Ecosystems & Environment, 71*(1-3), 19-35.

Bennet, J., & Morrisson, M. (1999). Valuing Wetland Rehabilitation. In W. Streever (Ed.), *An International Perspective on Wetland Rehabilitation*. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Berkes, F., Colding, J., & Folke, C. (2000). REDISCOVERY OF TRADITIONAL ECOLOGICAL KNOWLEDGE AS ADAPTIVE MANAGEMENT. *Ecological Applications, 10*(5), 1251-1262.

Berkhout, E. D., Schipper, R. A., Kuyvenhoven, A., & Coulibaly, O. (2010). Does heterogeneity in goals and preferences affect efficiency? A case study of farm households in northern Nigeria. *Agricultural Economics, 41*(3-4), 265-273.

Besmer, Y. L., Koide, R. T., & Twomlow, S. J. (2003). Role of phosphorus and arbuscullar mycorrhizal fungi on nodulation and shoot nitrogen content in groundnut and lablab bean. In Waddington (Ed.), *Grain*

Legumes and Green Manures for Soil Fertility in Southern Africa: Taking Stock of Progress (pp. 43-46). Vumba, Zimbabwe: Soil Fert Net and CIMMYT-Zimbabwe.

Bidogeza, J., Berentsen, P., De Graaff, J., & Oude Lansink, A. (2009). A typology of farm households for the Umutara Province in Rwanda. *Food Security, 1*(3), 321-335.

Blarel, B., Hazell, P., Place, F., and Quiggin, J. (1992). The Economics of Farm Fragmentation: Evidence from Ghana and Rwanda. *World Bank Economic Review, 6*(2), 233-254.

Bouyoucus, C. J. (1951). A calibration of the hydrometer method for making mechanical analysis of Soil *Science, 59*, 434-438.

Bray, H. R., & Kurtz, L. T. (1945). Determination of total organic and available forms of phosphorus in soils. *Soil Science, 9*, 39-46.

Breman, H., Fofana, B. and Mando A. . (2007). ''The Lesson of Drente's 'Essen': Soil Nutrient Depletion in Sub-Saharan Africa and Management Strategies for Soil Replenishment. In A. K. a. V. Braimoh, P.L.G (Ed.), *Land Use and Soil Resources* (pp. 145-166). Bonn, Germany: Springer + Business Media B.V.

Briggs, L., & Twomlow, S. J. (2002). Organic material flows within a smallholder highland farming system of South West Uganda. *Agriculture, Ecosystems & Environment, 89*(3), 191-212.

Brimingham, B. (1998). Learning local knowledge of soils: a focus on methodology. *Indigenous knowledge and Monitor,* ***6***(2), 7-10.

Brokensha, D., Warren, D., & Werner, O. (1980). *Indigenous Knowledge Systems and Development*. Lanham, MD University Press of America

Carsky, R. J., Berner, D. K., Oyewole, B. D., Dashiell, K., & Schulz. S. (2000). Reduction of Striga hermonthica parasitism on maize using soybean rotation. *International Journal Pest Management, 46*, 115-120.

Chambers, R., Pacey, A., & Trupp, L. (1989). *Farmers First, Farmer Innovation and Agricultural Research*. United Kingdom: Intermediate Technology Publications.

Chemonic International Inc. (2003). *Rwanda Environmental Threats and Opportunities Assessment*: USAID.

Chianu, J. N., Nkonya, E. M., Mairura, F. S., Chianu, J. N., & Akinnifesi, F. K. (2010). Biological nitrogen fixation and socioeconomic factors for legume production in sub-Saharan Africa: a review. *Agronomy for sustainable development*, 1-13.

CIALCA. (2008). *Final Report Phase I - CIALCA January 2006 - December 2008*: Consortium for Improving Agriculture-based Livelihoods in Central Africa.

Clay, D., Reardon, T., & Kangasniemi, J. (1998). Sustainable Intensification in the Highland Tropics: Rwandan Farmers' Investments in Land Conservation and Soil Fertility. *Economic Development and Cultural Change, 46*(2), 351-377.

Cobo, J. G., Dercon, G., Monje, C., Mahembe, P., Gotosa, T., Nyamangara, J., et al. (2009). Cropping strategies, soil fertility investment and land management practices by smallholder farmers in communal and resettlement areas in Zimbabwe. *Land Degradation & Development, 20*(5), 492-508.

Conelly, W., & Chaiken, M. (2000). Intensive Farming, Agro-Diversity, and Food Security Under Conditions of Extreme Population Pressure in Western Kenya. *Human Ecology, 28*(1), 19-51.

Crawford, T. W., Singh, Jr.U and Breman, H. (2008). Solving Agricultural Problems Related to Soil Acidity in Central Africa's Great Lakes Region (pp. 133). Kigali: IFDC CATALIST.

da Silva, P. M., Tsai, S. M., & Bonetti, R. (1993). Response to inoculation and N fertilization for increased yield and biological nitrogen fixation of common bean (*Phaseolus vulgaris* L.). *Plant and Soil, 152*, 123-130.

Dakora, F. D. (1984). Nodulation and nitrogen fixation by groundnut in amended and un-amended field soils in Ghana. In K. S. O. Ssali H. (Ed.), *Biological nitrogen fixation in Africa* (pp. 324–339).

Dakora, F. D., & Keya, S. O. (1997). Contribution of legume nitrogen fixation to sustainable agriculture in Sub-Saharan Africa. *Soil Biology and Biochemistry, 29*(5-6), 809-817.

de Graaf, J. (1996). *The price of soil erosion: an economic evaluation of soil conservation and watershed development*. Leiden: Mansholt studies V.3. Backhuys Publishers.

de Groot, R. S., Wilson, M. A., & Boumans, R. M. J. (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics, 41*(3), 393-408.

de Vos, L. (1986). *Rugezi wetlands: Use and functions*. Kigali: MINAGRI.

Denny, P., & Turyatunga, F. (1992). *Ugandan wetlands and their management* (Proceeding). Rennes, France: IUCN, Gland, Switzerland.

Devries, J. D., Bennett, J. M., Albrecht, S. L., & Boote, K. J. (1989). Water relations, nitrogenase activity and root development of three grain legumes in response to soil water deficits. *Field Crops Research, 21*(3-4), 215-226.

DeWalt, B. R. (1994). Using Indigenous Knowledge to Improve Agriculture and Natural Resource Management. *Human Organization, 53*(2), 123-131.

Dixon, A. B. (2002). The hydrological impacts and sustainability of wetland drainage cultivation in Illubabor, Ethiopia. *Land Degradation & Development, 13*(1), 17-31.

Dixon, A. B. (2005). Wetland sustainability and the evolution of indigenous knowledge in Ethiopia. *Geographical Journal, 171*(4), 306-323.

Dixon, A. B., & Wood, A. P. (2003). Wetland cultivation and hydrological management in eastern Africa: Matching community and hydrological needs through sustainable wetland use. *Natural resources forum, 27*(2), 117-129.

Drechsel, P., Gyiele, L., Kunze, D., & Cofie, O. (2001). Population density, soil nutrient depletion, and economic growth in sub-Saharan Africa. *Ecological Economics, 38*(2), 251-258.

Dugan, P. J. (1990). *Wetland Conservation: A review of Current Issues and Action* (IUCN, Gland, Switzerland ed.).

EIU. (2006). *Rwanda Water Energy Assessment Note*. Kigali: World Bank.

ELECTROGAZ. (2005). *2004-2005 Annual reports*. Kigali: ELECTROGAZ.

Ellison, A. M. (2004). Wetlands of Central America. *Wetlands Ecology and Management, 12*(1), 3-55.

Emerton, L., Iyango, L., Luwum, P., & Malinga, A. (1999). The economic value of Nakivubo Urban Wetland, Uganda. In K. a. I. Uganda National Wetlands Programme (Ed.), *The World Conservation Union, Eastern Africa Regional Office*. Nairobi.

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

Falkenmark, M., Finlayson, C., & Gordon, L. (2007). Agriculture, water, and ecosystems: avoiding the costs of going too far In D. Molden (Ed.), *Water for food, water for life: a comprehensive assessment of water management in agriculture* (pp. 234-277). Earthscan, London.

FAO. (1990). *Farm systems development. Guidelines for the conduct of a training course in farming systems development*. Rome.

Farrington, J., & Martin, A. M. (1988). Farmer participatory research: A review of concepts and recent fieldwork. *Agricultural Administration and Extension, 29*(4), 247-264.

Ferris, R. S. B. (2002). *Bean sub-sector market survey in Rwanda*. Kigali Rwanda: ATDT-CIAT/ISAR/IITA-FOODNET and PEARL Project.

Finlayson, C. (2007). Managing wetland ecosystems-balancing the water needs of ecosystems with those for people and agriculture. In C. King, J. Ramkissoon, M. Clusener-Godt & Z. Adeel (Eds.), *Water and ecosystems: managing water in diverse ecosystems to ensure well-being* (pp. 24-38): UNU, INWEH, Hamilton.

Finlayson, C. M., Davidson, N. C., Spiers, A. G., & Stevenson, N. J. (1999). Global wetland inventory – current status and future priorities. *Marine and Freshwater Research, 50*(8), 717-727.

Fofana, B., Breman, H., Carsky, R. J., Van Reuler, H., Tamelokpo, A. F., & Gnakpenou, K. D. (2004). Using mucuna and P fertilizer to increase maize grain yield and N fertilizer use efficiency in the coastal savanna of Togo. *Nutrient Cycling in Agroecosystems, 68*(3), 213-222.

GEF/World Bank. (2005). *Rwanda Integrated management of Critical Ecosystems Project*. Washington D.C: The World Bank.

Giller, K. E. (2002). Targeting management of organic resources and mineral fertilizers: Can we match scientists' fantasies with farmers' realities? In J. D. B. Vanlauwe, N. Sanginga and R. Merckx (Ed.), *Integrated Plant Nutrient Management in Sub-Saharan Africa: From Concept to Practice* (pp. 155-171). Wallingford U.K: CAB International in association with IITA.

Giller, K. E., Rowe, E. C., de Ridder, N., & van Keulen, H. (2006). Resource use dynamics and interactions in the tropics: Scaling up in space and time. *Agricultural Systems, 88*(1), 8-27.

GoR. (2004). Rwanda National Land Policy. In E. Ministry of Lands, Forestry, Water and Natural Resources (Ed.). Kigali.

GoR. (2005). Organic Law No. 08/2005 of 14/7/2005 Determining the Use and Management of Land in Rwanda. Kigali.

Gray, L. C., & Morant, P. (2003). Reconciling indigenous knowledge with scientific assessment of soil fertility changes in south-western Burkina Faso. *Geoderma, 111*(3-4), 425-437.

Grenier, L. (1998). *Working with Indigenous Knowledge. A guide for researchers*. Ottawa, ON, Canada: National library of Canada.

Habarurema, E., & Steiner, K. G. (1997). Soil suitability classification by farmers in southern Rwanda. *Geoderma, 75*(1-2), 75-87.

Haileslassie, A., Priess, J. A., Veldkamp, E., & Lesschen, J. P. (2007). Nutrient flows and balances at the field and farm scale: Exploring effects of land-use strategies and access to resources. *Agricultural Systems, 94*(2), 459-470.

Hategekimana, S. (2005). La dégradation actuelle du marais de Rugezi: une catastrophe écologique, *Mémoire de Licence*. Butare: Universite Nationale du Rwanda.

Hategekimana, S., & Twarabamenye, E. (2008). The impact on wetlands degradation on water resources management in Rwanda, *5th International Symposium on Environmental Hydrology*. Cairo, Egypt.

Helpage-Rwanda. (2004). *Mission d'étude de conservation et de gestion intégrée du Marais de Rugezi. Rapport provisoire*: MINALOC.

Herridge, D. F., Robertson, M. J., Cocks, B., Peoples, M. B., Holland, J. F., & Heuke, L. (2005). Low nodulation and nitrogen fixation of mungbean reduce biomass and grain yields. *Australian Journal of Experimental Agriculture, 45*(3), 269-277.

Hocking, P. J. (2001). Organic acids exuded from roots in phosphorus uptake and aluminium tolerance of plants in acid soils. In *Advances in Agronomy* (Vol. Volume 74, pp. 63-97): Academic Press.

Hollis, G. E. (1990). Environmental impacts of development on wetlands in arid and semi-arid lands. *Hydrological Sciences Journal, 35*(4), 411-428.

Huggins, C. (2009). Agricultural Policies and Local Grievances in Rural Rwanda. *Peace Review: A Journal of Social Justice, 21*(3), 296-303.

ISAR. (2005). *ISAR, Annual report 2005*. Kigali: ISAR.

Kagabo, D. M., Nsabimana, J.D, Mukuralinda, A. and Nabahungu, N.L. (2010). Performance of farmer-managed valley bottom irrigation system for rice production in Cyabayaga, Rwanda. In B. M. Mati (Ed.), *Agricultural Water Management Interventions Bearing Returns on Investment in Eastern and Southern Africa: A compendium of 18 Case studies from six countries in Eastern and Southern Africa* (pp. 203-213): ICRISAT, IFAD, ASARECA.

Kangalawe, R. Y. M., & Liwenga, E. T. (2005). Livelihoods in the wetlands of Kilombero Valley in Tanzania: Opportunities and challenges to integrated water resource management. *Physics and Chemistry of the Earth, Parts A/B/C, 30*(11-16), 968-975.

Kanyarukiga, S. G., & Ngarambe, V. (1998). *Rwanda country paper: Wetland characterization and classification for sustainable agricultural development.* Paper presented at the Proceedings of the Sub-Regional Consultation, Harare, Zimbabwe.

Kayiranga. D. (2006). *The Effect of land factors and management practices on Rice Yields, Case Study in Cyili inland Valley, Gikonko District, Rwanda.* ITC, Enschede, The Netherlands, Enschede.

Khan, D. F., Peoples, M. B., Schwenke, G. D., Felton, W. L., Chen, D., & Herridge, D. F. (2003). Effects of below-ground nitrogen on N balances of field-grown fababean, chickpea and barley. *Australian Journal of Agricultural Research, 54*, 333-340.

Kihara, J., Vanlauwe, B., Waswa, B., Kimetu, J. M., Chianu, J., & Bationo, A. (2010). Strategic phosphorus application in legume-cereal rotations increases land productivity and profitability in Western Kenya. *Experimental Agriculture, 46*(01), 35-52.

Kruseman, G. (2000). *Bio-economic household modelling for agricultural intensification.* Wageningen University and Research centre, Wageningen.

Kundiri, A. M., Jarvis, M. G., & Bullock, P. (1997). Traditional soil and land appraisal on fadama lands in northeast Nigeria. *Soil Use and Management, 13*(4), 205-208.

Lambert, D. (1996). Crop diversity and fallow management in a tropical deciduous forest shifting cultivation system. *Human Ecology, 24*(4), 427-453.

Landon, R. E. (1991). *Booker Tropical Soil Manual: A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics.* UK: Longman Scientific and Technical, Harlow.

Lema, A. J. (1996). *Cultivating the valleys: Vinyungu farming in Tanzania*. Earthscan, London.

Lewis, C. (2004). *Communication for Rural Innovation* (3rd ed.): Blackwell Publishing.

MA. (2005a). *Ecosystems and Human Well-Being: Wetlands and Water Synthesis*. Washington, D.C. USA: World Resources Institute.

MA. (2005b). *Ecosystems and Human Well-Being: Current State and Trends: Findings of the Condition and Trends Working Group (Millennium Ecosystem Assessment Series)*: Island Press.

Mahieu, S., Fustec, J., Faure, M.-L., Corre-Hellou, G., & Crozat, Y. (2007). Comparison of two 15N labeling methods for assessing nitrogen rhizo deposition of pea. *Plant and Soil, 295*(1), 193-205.

Marshall, C., & Rossman, G. B. (Eds.). (1999). *Designing Qualitative Research* (3rd Ed.
ed.). London: Sage Publications.

Martin, A., & Sherington, J. (1997). Participatory research methods--Implementation, effectiveness and institutional context. *Agricultural Systems, 55*(2), 195-216.

Masiyandima, M., Mc Cartney, M. P., & Van Koppen, B. (2004). *Wetland contributions to rural livelihoods in Zambia. FAO-Netherlands Partnership Program*. Pretoria: International Water Management Institute.

Mazzucato, V., & Niemeijer, D. (2000). *Rethinking soil and water conservation in a changing society. A case study in eastern Burkina Faso.* Wageningen.

Mbarushimana, K. D., & Nsabimana, J. D. (2008). *Agricultural Water Management Interventions with Proven Returns to Investment under Smallholder Systems. Findings from a Case study of Rwanda*: IMAWESA.

McCartney, M. P., & Houghton-Carr, H. A. (2009). Working Wetland Potential: An index to guide the sustainable development of African wetlands. *Natural Resources Forum, 33*(2), 99-110.

McCartney, M. P., & van Koppen, B. (2004). *Wetland contributions to livelihoods in United Republic of Tanzania*: FAO - Netherlands Partnership Programme, Food and Agriculture Organization of the United Nations, Rome, Italy.

McHugh, O. V., McHugh, A. N., Eloundou-Enyegue, P. M., & Steenhuis, T. S. (2007). Integrated qualitative assessment of wetland hydrological and land cover changes in a data scarce dry Ethiopian highland watershed. *Land Degradation & Development, 18*(6), 643-658.

McNeill, A., & Fillery, I. (2008). Field measurement of lupine belowground nitrogen accumulation and recovery in the subsequent cereal-soil system in a semi-arid Mediterranean-type climate. *Plant and Soil, 302*(1), 297-316.

Mellor. (2003). Agricultural Transformation for growth and employment in Rwanda. In MINECOFIN (Ed.). KIGALI.

MINAGRI. (2002). *Schema Directeur d'Aménagement des Marais, de protection des Bassins versants et de la conservation des sols: Rapport définitif 1ere phase, Rapport de synthese*. Kigali: MINAGRI.

MINAGRI. (2004). National agricultural policy, and strategic plan for transformation of agriculture in Rwanda. Kigali, Rwanda: Ministry of Agriculture and Animal Resources.

MINAGRI. (2008). Agricultural Sector Performance. First Semester 2008. Self Evaluation Report for joint Agricultural Sector Review 2008. In minagri (Ed.). Rwanda: MINAGRI.

MINALOC. (2004). *Mission d'étude de conservation et de gestion intégrée du Marais de Rugezi*. Kigali, Rwanda: MINALOC.

MINERENA. (2008). Five-year strategic plan for the environment and natural resources sector (2009-2013). Kigali.

MINIFRA. (2003). Stratégies nationale en matière de la qualité des ressources en eau au Rwanda (SNAQUE). Kigali.

Mitsch, W. J., & Gosselink, J. G. (2000). *Wetlands* (3rd Edition ed.). New York: John Wiley and Sons inc.

Morardet, S., & Tchamba, A. K. (2005). *Assessing trade-offs between agricultural production and wetlands preservation in Limpopo River Basin: a participatory framework*

Morris, M., Kelly, V., Kopicki, R., & Byerlee, D. (2007). *Fertilizer use in African agriculture: Lessons learned and good practice guidelines*. Washington DC: The World Bank.

Mosley, J. (2004). Land Policy in Rwanda: issues for UK Policy, *APPG Working Paper 3*. London.

Mowo, J. G., Kurothe, R. S., Shem, M. N., Kanuya, N. L., Dusengemungu, L., & Opondo, C. (2007). *Adopting the integrated watershed management approach in Rwanda: insights and lessons.* Paper presented at the National conference on agricultural research outputs, Kigali, Rwanda.

Mpepereki, S., Javaheri, F., Davis, P., & Giller, K. E. (2000). Soyabeans and sustainable agriculture: Promiscuous soya beans in southern Africa. *Field Crops Research, 65*(2-3), 137-149.

Mpepereki, S., Makonese, F., & Giller, K. E. (Eds.). (1996). *Soya beans in Smallholder Cropping Systems of Zimbabwe*. Harare, Zimbabwe: SoilFertNet/CIMMYT.

Mugabe, J. (1994). Research on Biofertilizers: Kenya, Zimbabwe and Tanzania. *Biotechnology and Development Monitor, 18*, 9-10.

Mukankomeje, R. (2010). Restoration of the Rugezi wetland. Retrieved 29 October, 2010

Murwira, H. K., Swift, M. J., & Frost, P. G. H. (1995). *Manure as a key resource in sustainable agriculture: a case study of communal area farming systems in Zimbabwe. A keynote address.* Paper presented at the Livestock and Sustainable Nutrient Cycling in Farming Systems of Sub-Saharan Africa, Addis Ababa, Ethiopia.

Musahara, B., & Gasarasi, L. (2005). *The land question in Kibungo Prvince*. Butare: University of Butare, Center for conflict Management.

Musahara, H. (2006). Improving Tenure Security for the Rural Poor. Rwanda - Country Case Study, *Improving Tenure Security for the Rural Poor* (pp. 19). Nakuru, Kenya: FAO.

Musoni, A. (2008). *Inheritance of resistance to fusarium wilt (F. oxysporum f. sp. phaseoli) and breeding multiple disease resistant and marketable high yielding climbing beans.* University of Nairobi, Nairobi.

Muthiri, J. (1993). *La Dégradation Actuelle du Marais de Rugezi: Une Catastrophe Ecologique*. Kigali, Rwanda.

Mwakalila, S. (2006). Socio-economic impacts of irrigated agriculture in Mbarali District of south-west Tanzania. *Physics and Chemistry of the Earth, Parts A/B/C, 31*(15-16), 876-884.

Mwalyosi. (1993, 27-29 November 1991). *Management of the Rufiji Delta as a wetland.* Paper presented at the Wetlands of Tanzania, Morogoro, Tanzania.

Nabahungu N.L, & Visser, S. M. (2011b). Contribution of wetland agriculture to farmer's livelihood in Rwanda. *Ecological Economics (in press)*.

Nabahungu, N. L., van Beek, C. L., Visser, S. M., Mowo, J. G., & Vanlauwe, B. (2011c). Nutrient resource flows in agricultural wetland and Hillside fields, as affected by farmer's resource endowment in Rwanda. *Agriculture, Ecosystems & Environment, Submitted*.

Nabahungu, N. L., & Visser, S. M. (2011a). Farmers' knowledge and perception of agricultural wetland in Rwanda *Land Degradation & Development (published on line)*.

Nandwa, S. M., & Bekunda, M. A. (1998). Research on nutrient flows and balances in East and Southern Africa: state-of-the-art. *Agriculture, Ecosystems & Environment, 71*(1-3), 5-18.

Naramabuye, F., Nabahungu N.L., Mukurarinda, A., & Nzeyimana, I. (2009). *Soil Health Program Business Planning Process*: Alliance for a Green Revolution in Africa.

National statistics Institute of Rwanda. (2007). *Enquête intermédiaire démographique et de santé. Rapport préliminaire*: NISR.

Ndakidemi, P. A., Dakora, F. D., Nkonya, E. M., Ringo, D., & Mansoor, H. (2006). Yield and economic benefits of common bean (*Phaseolus vulgaris*) and soybean (Glycine max) inoculation in northern Tanzania. *Australian Journal of Experimental Agriculture, 46*, 571-577.

Ngarambe, V., & Kanyarukiga, S. G. (1998). *Wetland characterization and classification for sustainable agricultural development*. Kigali: MINAGRI.

Niemeijer, D., & Mazzucato, V. (2003). Moving beyond indigenous soil taxonomies: local theories of soils for sustainable development. *Geoderma, 111*(3-4), 403-424.

NISR. (2008). EICV Poverty Analysis for the Economic Development strategy (EICV III). In NSIR (Ed.). Kigali: National Statics Institute of Rwanda.

Nkonya, E., Kaizzi, C., & Pender, J. (2005). Determinations of nutrient balances in a maize farming system in eastern Uganda. *Agricultural Systems, 85*, 155-182.

Odame, H. (1997). Biofertilizer in Kenya: Research, production and extension dilemmas. *Biotechnology and Development Monitor, 30*, 20-23.

Oikeh, S., Houngnandan, P., Abaidoo, R., Rahimou, I., Touré, A., Niang, A., et al. (2010). Integrated soil fertility management involving promiscuous dual-purpose soybean and upland NERICA enhanced rice productivity in the savannahs. *Nutrient Cycling in Agroecosystems, 88*(1), 29-38.

Ojiem, J., Vanlauwe, B., de Ridder, N., & Giller, K. (2007). Niche-based assessment of contributions of legumes to the nitrogen economy of Western Kenya smallholder farms. *Plant and Soil, 292*(1), 119-135.

Okalebo, J., Palm, C. A., Lekasi, J. K., Nandwa, S. M., Otieno, C. O., Waigwa, M., et al. (2003). *Use of organic and inorganic resources to increase maize yield in some Kenyan infertile soils: A five-year experience*. Nairobi Kenya: Academy science.

Ortmann, G. F., & King, R. P. (2007). Agricultural Cooperatives I: History, Theory and Problems. *Agrekon: Agricultural Economics Research, Policy and Practice in Southern Africa, 46*(1), 18 - 46.

Oudwater, N., & Martin, A. (2003). Methods and issues in exploring local knowledge of soils. *Geoderma, 111*(3-4), 387-401.

Pannell, D. (1999). Social and economic challenges in the development of complex farming systems. *Agroforestry Systems, 45*(1), 395-411.

Peoples, M., Brockwell, J., Herridge, D., Rochester, I., Alves, B., Urquiaga, S., et al. (2009). The contributions of nitrogen-fixing crop legumes to the productivity of agricultural systems. *Symbiosis, 48*(1), 1-17.

Peoples, M. B., Faizah, A. W., Rerkasem, B., & Herridge, D. F. (Eds.). (1989). *Methods for evaluating nitrogen fixation by nodulated legumes in the field*. Australia: ICIAR Canberra.

Peoples, M. B., Turner, G. L., Shah, Z., Shah, S. H., Aslam, M., Ali, S., et al. (1997). *Evaluation of the 15N natural abundance technique to measure N2-fixation in experimental plots and farmers' fields.* Paper presented at the Extending nitrogen fixation research to farmers' field: proceedings of the international workshop on managing legume nitrogen fixation in the cropping systems of Asia, Hyderabad, India.

Pieri, C. (1989). *Fertilité des terres de savanes* SIRAD Institut de recherche agronomique tropicales.

Polson, R. A., & Spencer, D. S. C. (1991). The technology adoption process in subsistence agriculture: The case of cassava in South-western Nigeria. *Agricultural Systems, 36*(1), 65-78.

Pottier, J. (2006). Land Reform for Peace? Rwanda's 2005 Land Law in Context. *Journal of Agrarian Change, 6*(4), 509-537.

Ramsar. (1971). The Convention on Wetlands: An Active Player in the Fight Against Poverty.

Ramsar Convention secretariat. (Ed.). (2007). *Addressing changes in ecological character of Ramsar sites and other wetlands.* (Third edition). Gland, Switzerland: Ramsar handbooks for the wise use of wetlands.

Ramsar. (2000). *Wise Use of Wetlands. Handbook 1*. Gland, Switzerland: Ramsar Convention Bureau.

Rebelo, L. M., McCartney, M., & Finlayson, C. (2009). Wetlands of Sub-Saharan Africa: distribution and contribution of agriculture to livelihoods. *Wetlands Ecology and Management*.

REMA. (2006). Economic analysis of natural resource management in Rwanda. Kigali.

REMA. (2009). Rwanda State of Environment and Outlook: Our Environment for Economic Development. In REM Authority (Ed.) (pp. 137). Kigali.

REMA. (2008). *Etablissement d'un inventaire national rapide des marais et élaboration de cinq avant projets d'arrêts ministériels relatifs aux marais (4 modules)* Kigali, Rwanda: Office Rwandais de Protection de l'environnement (REMA).

Roggeri, H. (1998). *Tropical Freshwater wetlands: A guide to current Knowledge and Sustainable Management*: Kluwer, Dordrecht.

Roose, E., & Ndayizigiye, F. (1997). Agroforestry, water and soil fertility management to fight erosion in tropical mountains of Rwanda. *Soil Technology, 11*(1), 109-119.

RSSP. (2001). *Project appraisal document for the Rwanda Rural Sector Support Programme*. Kigali.

Rutunga, V., Steiner, K. G., Nancy, K. K., Gachene, C. K., & Nzabonihankuye, G. (1998). Continuous fertilization on non-humiferous acid Oxisols in Rwanda "Plateau Central": Soil chemical changes and plant production. *Biotechnogy, Agronomy Society and Environment 2*(2), 135-142.

Rutunga V., B. H. J., Stephan Mantel and Marc Janssens. (2007). Soil use and management strategy for raising food and cash output in Rwanda. *Journal of Food, Agriculture & Environment 5*(3&4), 434-441.

Safari, B. (2010). A review of energy in Rwanda. *Renewable and Sustainable Energy Reviews, 14*(1), 524-529.

Salvagiotti, F., Cassman, K. G., Specht, J. E., Walters, D. T., Weiss, A., & Dobermann, A. (2008). Nitrogen uptake, fixation and response to fertilizer N in soybeans: A review. *Field Crops Research, 108*(1), 1-13.

Sanginga, N., Dashiell, K. E., Diels, J., Vanlauwe, B., Lyasse, O., Carsky, R. J., et al. (2003). Sustainable resource management coupled to resilient germplasm to provide new intensive cereal-grain-legume-livestock systems in the dry savannah. *Agriculture, Ecosystems & Environment, 100*(2-3), 305-314.

Sanginga, N., Thottappilly, G., & Dashiell, K. (2000). Effectiveness of rhizobia nodulating recent promiscuous soybean selections in the moist savannah of Nigeria. *Soil Biology and Biochemistry, 32*(1), 127-133.

Sanginga, N., & Woomer, P. (2009). Integrated Soil Fertility Management in Africa: Principles, Practices and Developmental process. Nairobi-Kenya: TSBF-CIAT.

Schuyt, K. D. (2005). Economic consequences of wetland degradation for local populations in Africa. *Ecological Economics, 53*(2), 177-190.

Schwenke, G. D., Felton, W. L., Herridge, D. F., Khan, D. F., & Peoples, M. B. (2002). Relating particulate organic matter-nitrogen (POM-N) and non-POM-N with pulse crop residues, residue management and cereal N uptake. *Agronomy, 22*(7-8), 777-787.

Scoones, I. (1991). Wetlands in Drylands: Key Resources for Agricultural and Pastoral Production in Africa. *Ambio, 20*(8), 366-371.

Serraj, R., Sinclair, T. R., & Purcell, L. C. (1999). Symbiotic N2 fixation response to drought. *Journal of Experimental Botany, 50*(331), 143-155.

Shah, A. (1998). Watershed Development Programmes in India: Emerging Issues for Environment-Development Perspectives. *Economic and Political Weekly, 26*(33), 66-79.

Shearer, G. B., & Kohl, D. H. (1986). N2-fixation in field settings: estimations based on natural 15N abundance. *Australian Journal of Plant and Physics, 13*, 699-756.

Silvius, M. J., Oneka, M., Verhagen, A. (2000). Wetlands: Lifeline for people at the edge. *Physics and Chemistry of the Earth (B), 25*(7-8), 645-652.

Sinclair, T. R., Muchow, R. C., Bennet, J. M., & Hammond, L. C. (1987). Relative sensitivity of nitrogen and biomass accumulation to drought in field-grown soybean. *Agronomy Journal, 79*, 986-991.

Sissoko, K. (1998). *Et demain l'agriculture? : options techniques et mesures politiques pour un développement agricole durable en Afrique subsaharienne : cas du Cercle de Koutiala en zone sud du Mali* Wageningen : Wageningen Université et Centre de Recherche, Wageningen.

Smaling, E. M. A., Roscoe, R., Lesschen, J. P., Bouwman, A. F., & Comunello, E. (2008). From forest to waste: Assessment of the Brazilian soybean chain, using nitrogen as a marker. *Agriculture, Ecosystems & Environment, 128*(3), 185-197.

Smaling, E. M. E., Fresco, L.O., de Jager, A.,. (1996). Classifying and monitoring soil nutrient stocks and flows in African agriculture. *Ambio, 25*, 235-256.

Sperling, L., Scheidegger, O., Burachura, R., Nyabyenda, P., & Munyaneza, S. (1992). Intensifying production among smallholder farmers: The impact of improved climbing beans (pp. 13). Butare, Rwanda: CIAT/RESAPAC.

Steiner, K. G. (1998). Using farmers' knowledge of soils in making research results more relevant to field practice: Experiences from Rwanda. *Agriculture, Ecosystems & Environment, 69*(3), 191-200.

Stolzenbach, A. (1994). Learning by improvisation : Farmers' experimentation in Mali. In I. S. a. J.Thompson (Ed.), *Beyond farmer first. Rural people's knowledge, Agricultural research and extension practice* (pp. 155-159). London: Intermediate technology publications.

Stone, G. D., Netting, R. M., & Stone, M. P. (1990). Seasonality, Labor Scheduling, and Agricultural Intensification in the Nigerian Savannah. *American Anthropologist, 92*(1), 7-23.

Stroorvogel, J. J., Smaling, E.M.A. (1990). *Assessment of soil nutrient depletion in sub-sahara Africa*. Wageningen- Netherland: DLO Winand Starring Centre for Integrated Land, Soil and Water Reseach(SC-DLO).

Tenge, A. J., Graaff, J. D., & Hella, J. P. (2004). Social and economic factors affecting the adoption of soil and water conservation in West Usambara highlands, Tanzania. *Land Degradation & Development, 15*(2), 99-114.

Thies, J. E., Woomer, P. L., & Singleton, P. W. (1995). Enrichment of Bradyrhizobium spp populations in soil due to cropping of the homologous host legume. *Soil Biology and Biochemistry, 27*(4-5), 633-636.

Tittonell, P., Vanlauwe, B., Leffelaar, P. A., Rowe, E. C., & Giller, K. E. (2005). Exploring diversity in soil fertility management of smallholder farms in western Kenya: I. Heterogeneity at region and farm scale. *Agriculture, Ecosystems & Environment, 110*(3-4), 149-165.

Turner, R. K., van den Bergh, J. C. J. M., Söderqvist, T., Barendregt, A., van der Straaten, J., Maltby, E., et al. (2000). Ecological-economic analysis of wetlands: scientific integration for management and policy. *Ecological Economics, 35*(1), 7-23.

Turpie, J. K. (2000). *The use and value of natural resources of the Rufiji floodplain and delta, Tanzania*. Cape Town, South Africa: Eastern Africa Regional Office; Fitzpatrick Institute, University of Capetown.

Umoh, G. (2008). The promise of wetlands farming: Evidence from Nigeria. *Agricultural Journal, **3***(2), 107-112.

van Beek, C., Onduro, D., Gachimbi, L., & de Jager, A. (2009). Farm nitrogen flows of four farmer field schools in Kenya. *Nutrient Cycling in Agroecosystems, 83*(1), 63-72.

van de Fliert, E., & Braun, A. R. (2002). Conceptualizing integrative, farmer participatory research for sustainable agriculture: From opportunities to impact. *Agriculture and Human Values, 19*(1), 25-38.

Van den Bosch, H., De Jager, A., and Vlaming, J. (1998). Monitoring nutrient flows and economic performance in African farming systems (NUTMON): II. Tool development. *Agriculture, Ecosystems & Environment, 71*.

Vanlauwe, B., Aihou, K., Aman, S., Iwuafor, E. N. O., Tossah, B. K., Diels, J., et al. (2001). Maize Yield as Affected by Organic Inputs and Urea in the West African Moist Savanna. *Agron. J., 93*(6), 1191-1199.

Vanlauwe, B., & Giller, K. E. (2006). Popular myths around soil fertility management in sub-Saharan Africa. *Agriculture, Ecosystems & Environment, 116*(1-2), 34-46.

Vanlauwe, B., Tittonell, P., & Mukalama, J. (2006). Within-farm soil fertility gradients affect response of maize to fertiliser application in western Kenya. *Nutrient Cycling in Agroecosystems, 76*(2), 171-182.

Verdoodt, A., & Van Ranst, E. (2006). Environmental assessment tools for multi-scale land resources information systems: A case study of Rwanda. *Agriculture, Ecosystems & Environment, 114*(2-4), 170-184.

Visser, S. M., Leenders, J. K., & Leeuwis, M. (2003). Farmers' perceptions of erosion by wind and water in northern Burkina Faso. *Land Degradation & Development, 14*(1), 123-132.

Walkley, A., & Black, C. A. (1934). An examination of the Degtjareff method for determining soil organic matter and a proposal modification of the chromic acid titration method. *Soil Science, 37*, 29-38.

Weber, G., Elemo, K., Lagoke, S. T. O., Awad, A., & Oikeh, S. (1995). Population dynamics and determinants of Striga hermonthica on maize and sorghum in savannah farming systems. *Crop Protection, 14*(4), 283-290.

Whitlow, J. R. (1983). Vlei cultivation in Zimbabwe: Reflections on the past. *Zimbabwe Agricultural Journal*(80), 123-135.

Willetts, E. (2008). *Watersheds Payments for Ecosystems services and climate change adaptation: Rugezi wetlands, Rwanda.* Duke University.

Wood A., P., & Dixon A., B. (2002). *Sustainable wetland management in Illubabor Zone*. Huddersfield, UK: Huddersfield University.

Wood, A. P. (1996). Wetland drainage and management in south-west Ethiopia: Some environmental experiences of an NGO. In M. H. S. Reenburg A, Nielsen I (Ed.), *The Sahel Workshop 1996*. Institute of Geography, University of Copenhagen, Copenhagen.

World Bank. (2005). *Integrated Management of Critical Ecosystems Project*.

Yanggen, D., Kelly, V., Reardon, T., & Naseem, A. (1998). *Incentives for fertilizer use in sub-Saharan Africa: A review of empirical evidence on fertilizer response and profitability*. East Lansing, USA: Department of Agricultural Economics, Michigan State University.

ZAMAN-ALLAH, M., SIFI, B., L'TAIEF, B., EL AOUNI, M. H., & DREVON, J. J. (2007). Rhizobial inoculation and P fertilization response in common bean (*Phaseolus vulgaris*) under glasshouse and field conditions. *Experimental Agriculture, 43*(01), 67-77.

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

Summary

Summary

The aim of this research was to identify appropriate options for improved wetland management in Rwanda, with a focus on agricultural use of wetlands. This research was executes in two sites namely Rugeramigozi, Southern Province; and Cyabayaga, Eastern Province. The Cyabayaga and Rugeramigozi wetlands were selected as representatives of typical wetland agriculture in Rwanda. Rugeramigozi lies in the highly populated central plateau zone of Rwanda where pressure on land is high. In Cyabayaga, land pressure is lower and soil fertility is better compared to Rugeramigozi.

An overview study of wetlands in Rwanda was conducted with the objective to analyse their functions, problems and opportunities. Cultivated wetlands are covering up to 148 344 ha of land and play an important role in supporting farmers' livelihood through agriculture activities. The analysis showed that wetlands form very fragile ecosystems that should be regarded as a critical component of long term livelihood and natural resource management strategies, rather than as resources to be utilized as quick fix solutions. A balance between conservation and utilisation of wetlands should be the driving factor in development of wetlands.

Agricultural management strategies in existing cultivated wetlands were analysed to investigate farmers' knowledge and perception of agricultural wetland management in two typical reclaimed wetland in Rwanda. A combination of a household survey, focus group discussions and a transect walk was used for that purpose. The major constraints for agricultural production identified by farmers in the two wetlands were water shortage, low availability of improved seeds and high prices of inorganic fertilizers. Food crop production for family consumption was identified by farmers in Rugeramigozi wetland as the primary benefit whereas income generation was considered to be the primary benefit in Cyabayaga. Rice is an important cash crop in both wetlands, but whereas farmers in Cyabayaga wish to continue growing rice farmers in Rugeramigozi want to grow rice only after it has been tested for its adaptability.

A study on income generated from wetland cultivation using focus group discussion, formal surveys and the Monitoring for Quality Improvement (MONQI) tool showed that the per household per year contribution of wetland cultivation to gross margin (GM) was 74% ($ 1901) of total household income in Cyabayaga, compared to 24% ($ 84) in Rugeramigozi. The rice in Cyabayaga was the largest contributor to household income providing an average $ 1045 per household per season while vegetables cultivated in the dry season in Rugeramigozi have a high potential as cash crops.

Information on resource flow and use strategies was collected within farming households managing wetland and hillside fields in Cyabayaga and Rugeramigozi catchments of Rwanda. Differences between hillside, wetland and farmer resource groups based on resources were observed for inputs use (e.g. 9.4 to 169.0 N kg ha^{-1}), output (e.g. 24 to 134.5 N kg ha^{-1}), partial nutrients (e.g.-4.8 to 34.5 N kg ha^{-1}) balance and general soil fertility status. Nutrient inputs, outputs and partial nutrients balance are higher in Cyabayaga compared to Rugeramigozi except for P. Results showed that agricultural potential, farming system (choice of crops), access to resources, gross margin, size of livestock herd and farmers resource endowment influence the magnitude and the degree to which nutrients fluxes may be imbalanced. This study highlights the assertion that farmers may not necessarily be concentrating nutrients around their homestead because of the short distance. Rather, farmers apply nutrients in plots which they perceive to be fertile and secure to produce satisfactory yields. This is illustrated by the rice crop in wetland (far from homestead), which receive more inorganic fertilisers compared to other crops mainly because of the return that rice provides to the farmers. Thus, the amount of resources used at the farm level is closely tied to the potential increase in productivity to be gained. The value and marketability of the crops produced are therefore critical factors in the decision to invest in soil fertility improvement.

The improvement of soil fertility is critical since nutrient balances were negative in all wetlands. Therefore an integrated soil fertility management (ISFM) involving a nitrogen-fixing grain legume, farmyard

manure (FYM) and limited amounts of inorganic fertilizer, was tested for grain legume and maize productivity. A multi-location trial was laid out at two sites on three landscape positions (valley, bottoms, foot slopes and hillsides). The cropping system factor contained three levels: continuous maize-maize cultivation, bean (*Phaseolus vulgaris* L.) -maize (*Zea mays* L.) rotation, and soybean (*Glycine max* (L.) Merr.) -maize rotation. Fertilizer application contained three levels: no fertilizer, FYM and FYM + diamonium phosphate (DAP) applied only in the first season. N-fixation of bean and soybean was assessed using the 15N natural. The results showed that maize grain yield was 2.6 t ha^{-1} in Rugeramigozi and 4.2 t ha^{-1} in Cyabayaga. Beans had highest yields in Rugeramigozi (0.7 t ha^{-1}), while soybean in Cyabayaga soybean (1.4 t ha^{-1}). In general legume and maize yields were lowest on the hillside plots. Fertilizer application increased grain yield, shoot dry matter and N accumulation of both legumes and maize with the highest yield observed in the treatment combining FYM and DAP. Maize yield after legume was higher than continous maize production for the two seasons studied. The N balance was negative in both sites at all landscape positions and under all fertilizer applications. This proves that maize yield response after legume is not only attributable to improvements in soil N supply through N fixation but that there are residual and indirect effects.

The key findings of this research are as following.

1. Communication between the relevant ministries – environment, lands, economic planning and finance, agriculture and tourism - is inefficient or non-existent at present in Rwanda.
2. Lack of data and stakeholder interaction on which to base policy development and decision making leads to poor policy design, exacerbating user conflicts resulting in poor wetland management.
3. Promising strategies for improved wetland management exist.

Examples of promising strategies from this thesis include involvement of the full range of wetlands stakeholders in issue evaluation and strategy development; collaboration between scientists, engineers, farmers and extension regarding terminology and development of sustainable cropping programs and recommendations; introduction of crop varieties more suited to the wetland conditions; locally adapted policy development and economic incentives to reduce farmer risk and support investment; and more site specific selection of crops and fertilizer types and programs.

The main message of this thesis is that wetlands should be recognized as a critical component for long-term livelihood and environment functions. Therefore, more attention must be given to the development and adoption of sustainable wetland use technologies that meet the needs of both local communities and the hydrological system. Integrated watershed management is an opportunity for more sustainable management of wetlands. Increased communication between all stakeholders, informed by actual social and environmental data, holds great potential achieving this goal.

Samenvatting

Het doel van dit onderzoek was het identificeren van geschikte opties voor verbetering van het beheer van wetlands in Rwanda, met een focus op het agrarisch gebruik van wetlands. Het onderzoek werd uitgevoerd in twee locaties, namelijk Rugeramigozi, gelegen in de Zuidelijke Provincie, en Cyabayaga gelegen in de Oostelijke Provincie. De Cyabayaga en Rugeramigozi wetlands zijn representatieve gebieden voor agrarische gebruik van wetlands in Rwanda. Rugeramigozi ligt in de dichtbevolkte Midden-plateau zone van Rwanda, waar de bevolkingsdruk hoog is. Cyabayaga heeft een betere bodemvruchtbaarheid en lagere bevolkingsdruk in vergelijking met Rugeramigozi.

Met als doel de functies van wetlands te analyseren en problemen en kansen met betrekking tot het beheer van wetlands te identificeren werd een overzichtsstudie van wetlands in Rwanda uitgevoerd. De totale oppervlakte van wetlands met landbouw is 148344 ha in Rwanda. De analyse toonde aan dat wetlands zeer kwetsbare ecosystemen zijn en een essentiële bijdrage leveren aan het levensonderhoud van boeren. Ze vormen tevens een kritieke factor bij het beheer van natuurlijke hulpbronnen. Wetlands kunnen niet worden gebruikt als quick fix oplossing voor een economisch probleem. Bij de ontwikkeling van wetlands moet het evenwicht tussen de instandhouding en het gebruik van wetlands de drijvende factor zijn.

Landbouw management strategieën in twee gereclameerde wetlands, Rugeramigozi and Cyabayaga werden geanalyseerd om de kennis van de boeren met betrekking tot duurzaam beheer van wetlands te onderzoeken. Interviews met huishoudens, focusgroep discussies en transect wandelingen met boeren uit de regio leverden informatie over management strategieën, productie beperkende factoren en gewenste gewassen. De belangrijkste hindernissen voor landbouwproductie, geïdentificeerd door de boeren in deze twee wetlands, waren water tekort, geringe beschikbaarheid van verbeterd zaaigoed en de hoge prijzen van anorganische meststoffen. Voedsel productie voor eigen consumptie werd door boeren in Rugeramigozi wetland geïdentificeerd als het belangrijkste voordeel van landbouw in de wetlands terwijl het genereren van inkomsten in Cyabayaga als het belangrijkste voordeel werd beschouwd. Rijst is in beide wetlands een belangrijk marktgewas, maar hoewel boeren in Cyabayaga rijst willen blijven produceren, willen boeren in Rugeramigozi pas weer rijst gaan verbouwen nadat het gewas is getest op haar lokale aanpassingsvermogen.

Een studie naar de inkomsten uit landbouw in de wetlands, waarbij gebruik werd gemaakt van focusgroep discussies, formele enquêtes en de MONitoring voor Quality Improvement (MONQI) tool, toont aan dat de bijdrage van akkerbouw in de wetlands in Cyabayaga 74% ($ 1901) van het totale bruto inkomen van het huishouden per jaar is. Dit is hoog in vergelijking met Rugeramigozi, waar de bijdrage van wetlands aan het bruto inkomen slechts 24% ($ 84) per jaar is. Rijst leverde de grootste bijdrage aan het gezinsinkomen in Cyabayaga, gemiddeld 1045 dollar per huishouden per seizoen. In Rugeramigozi heeft fruitteelt in het droge seizoen een groot potentieel als cash gewas.

In beide wetlands werd met de MONQI tool en bodemanalyses informatie verzameld over het strategisch gebruik en het effect van beschikbare middelen als mest, geld en nutriënten. Er werden verschillen in input (bijv. 9,4 tot 169,0 N kg ha^{-1}), output (bv 24 tot 134,5 kg N ha^{-1}), nutriëntenbalansen (bijv.-4,8 tot 34,5 N kg ha^{-1}) en in bodemvruchtbaarheid status waargenomen, zowel tussen velden op de hellingen en in de wetlands als tussen de velden van boeren met verschillende welvaart. De nutriëntenbalans en de in- en output van voedingsstoffen voor het gewas zijn in Cyabayaga hoger dan in Rugeramigozi met uitzondering van P. De resultaten toonden aan dat de omvang van de nutriëntenbalans en de mate waarin deze uit evenwicht kan raken worden beïnvloed door de keuze van het agrarische systeem, de toegang tot hulpmiddelen, de omvang van de veestapel en de natuurlijke hulpbronnen van de boeren. Deze studie spreekt de algemeen geaccepteerde bewering dat boeren in ontwikkelingslanden voedingsstoffen concentreren rond hun boerderij vanwege de korte afstand tegen. Integendeel, de boeren

gebruiken hun beschikbare middelen juist op de percelen die zij zien als vruchtbaar en waarvan ze denken een goede opbrengst te kunnen halen, ongeacht de afstand tot hun boerderij. Dit wordt geïllustreerd door de productie van rijst in de wetlands, die relatief ver van de woning liggen. Op deze velden worden meer anorganische meststoffen toegevoegd zowel in vergelijking met velden met andere gewassen in de wetlands als in vergelijking met velden op de helling. Volgens de boeren is dit vooral gerelateerd aan het te verwachten rendement van rijst. Dus de hoeveelheid middelen die worden gebruikt is nauw verbonden met de potentiële stijging van de te behalen productiviteit. De waarde en verkoopbaarheid van de geproduceerde gewassen zijn daarom cruciale factoren in de beslissing om te investeren in verbetering van de bodemvruchtbaarheid.

Een verbetering van de bodemvruchtbaarheid is van essentieel belang, omdat nutriëntenbalansen negatief waren op alle velden zowel in de wetlands als op de hellingen. Daarom is een test uitgevoerd met een geïntegreerde beheerstrategie ten behoeve van verbetering van de bodemvruchtbaarheid. De geïntegreerde strategie bestond uit een combinatie van stikstof fixerende zaaddragende leguminosen, stalmest en beperkte hoeveelheden anorganische meststoffen. Het effect van de strategie werd getoetst door middel van de productiviteit van mais en leguminosen. Een multi-locatie proef werd aangelegd in de twee wetlands op drie posities in het landschap (het wetland, de voet van de hellingen en op de helling). Drie verschillende gewasrotatie systemen werden getest; continue maïs-maïs teelt, boon (*Phaseolus vulgaris L.*)-maïs (*Zea mays L.*) rotatie en sojabonen (*Glycine max (L.) Merr.*)-Mais rotatie. Veder werden er drie niveaus van bemesting toegepast in het eerste seizoen: geen kunstmest, stalmest en stalmest + di-amonium fosfaat (DAP). N-fixatie van bonen en soja werd beoordeeld met behulp van de 15N analysemethode. De resultaten toonden aan dat de maïs opbrengst in Rugeramigozi 2,6 t ha^{-1} was en 4,2 t ha^{-1} in Cyabayaga. Bonen hadden de hoogste opbrengst in Rugeramigozi (0,7 t ha^{-1}), terwijl de soja in Cyabayaga het best produceerde (1,4 ha t^{-1}). Over het algemeen was de opbrengst van leguminosen en maïs het laagst op percelen op de helling. Bemesten verhoogt de graanopbrengst en versnelt N-accumulatie in zowel peulvruchten en mais. De hoogste opbrengst werd waargenomen bij de gecombineerde behandeling van stalmest en DAP bij maïs. De maïs opbrengst na peulvruchten was hoger dan de continue productie van maïs voor de bestudeerde twee seizoenen. De N-balans was negatief in beide locaties op alle posities in het landschap en onder alle bemestingschema's. Dit bewijst dat de verhoogde maïs opbrengst na peulvruchten niet alleen toe te schrijven is aan het verhoogde N-aanbod in de bodem dankzij N-fixatie, maar dat er ook rest en indirecte effecten invloed hebben op de gewas opbrengst.

De belangrijkste bevindingen van dit onderzoek zijn:

1. Op dit moment is communicatie tussen de relevante Rwandese ministeries, betrokken bij beleidsvorming voor wetlandgebruik inefficiënt of niet bestaand.
2. Beleidsvorming en besluitvorming voor wetlandgebruik worden gehinderd door het ontbreken van informatie en gebrek aan interactie tussen belanghebbenden. Dit leidt tot slecht beleidsontwerp, verergert conflicten tussen gebruikers en resulteert uiteindelijk in een slecht beheer van wetlands.
3. Er zijn veelbelovende strategieën voor een betere agrarisch beheer van wetlands beschikbaar.

Voorbeelden van kansrijke strategieën uit dit proefschrift zijn het realiseren van betrokkenheid van alle belanghebbenden in evaluaties van wetlandbeheer strategieën en nieuwe strategie ontwikkeling; optimaliseren van samenwerking tussen wetenschappers, landbouwadviseurs en boeren ten aanzien van de terminologie, de ontwikkeling van duurzame teeltsystemen en het geven van aanbevelingen; de invoering van gewasrassen die aangepast zijn aan de omstandigheden in het specifieke wetland; het ontwikkelen van lokaal aangepast beleid, het ontwikkelen van economische stimulansen ter vermindering van de investerings risico's voor de boer, en meer site specifieke selectie van gewassen en bemesting-schema's.

De belangrijkste boodschap van dit proefschrift is dat wetlands moeten worden erkend als een essentieel onderdeel van het levensonderhoud van boeren en een kritieke factor zijn bij het duurzame beheer van natuurlijke hulpbronnen. Daarom moet meer aandacht worden besteed aan de ontwikkeling en invoering van duurzaam gebruik van wetland technologieën die aan de behoeften van zowel de lokale gemeenschappen en het hydrologische systeem voldoen. Geïntegreerd beheer van stroomgebieden is een kans voor meer duurzaam beheer van wetlands. Verbetering van de communicatie tussen alle belanghebbenden, ondersteund sociale en ecologische gegevens, heeft een groot potentieel voor het bereiken van duurzaam beheer van wetlands.

PE&RC PhD Education Certificate

With the educational activities listed below the PhD candidate has complied with the educational requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

Review of literature (4.5 ECTS)
- Sustainable agricultural wetland management

Writing of project proposal (4 ECTS)
- Options of improved management of agricultural wetlands in Rwanda

Post-graduate courses (9.5 ECTS)
- Farming systems modelling and trade-off analysis; TSBF (2008)
- The art of modelling; PE&RC (2008)
- Multivariate analysis; PE&RC (2008)
- Climate change and integrated watershed management; PE&RC (2008)
- Linear models; PE&RC (2010)
- Mixed linear model; PE&RC (2010)

Laboratory training and working visits (3 ECTS)
- MonQI monitoring & evaluation; FARA project (2009)
- Legume-Rhizobium symbiosis; ESRI (2010)

Deficiency, refresh, brush-up courses (9 ECTS)
- Integrated watershed management (2006)
- GIS and remote sensing for water and land management (2007)

Competence strengthening / skills courses (1.6 ECTS)
- Scientific writing; ISAR (2008)
- One-day symposia on the use of end-note; (2010)
- One-day symposia on paper writing and publication (2010)

PE&RC Annual meetings, seminars and the PE&RC weekend (0.9 ECTS)
- Annual PE&RC days (2006, 2010)
- NWO Talent day (2009)

Discussion groups / local seminars / other scientific meetings (7.7ECTS)
- Butare University PhD meetings (2007-2009)
- TSBF Meetings: meetings with scientific staff from CIAT on project progress (2007-2009)
- ISAR Scientific days; (2008, 2009, 2010)

International symposia, workshops and conferences (4.5 ECTS)
- Integrated watershed management for adaptation to climate change; the candidates from more than 10 nationalities, had to present a poster of their research; Kerkrade, the Netherlands (2008)
- African Soil Science Society, annual meetings (2009, 2010)

Lecturing / supervision of practical's / tutorials (15 ECTS)
- Integrated watershed management practical; 10 days (2007)
- Integrated watershed management; 45 days (2008-2010)

Supervision of 2 MSc students (8 days)
- Characterizing resource use strategies in selected wetlands in Rwanda
- Farmers' views and perceptions of soil erosion and conservation in Southern province of Rwanda

Curriculum vitae and author's publications

Nsharwasi Léon Nabahungu was born on 26 July 1966 in Bukavu, Democratic Republic of Congo (D.R. Congo). He finished his secondary school at Alfajiri Insitute in 1986, Bukavu, where he obtained his high school certificate in mathematics and physics. He entered the University of Yangambi (Institut facultaire des Sciences Agronomiques) and obtained a degree of Ingénieur Agronome with specialization in Soil sciences in 1993. Till 1994, he was doing family business as driver of a small lorry in Bukavu. In 1995, he was employed at Institut des Sciences Agronomiques du Rwanda (ISAR, Rwanda) as a research assistant in the area of soil conservation and improvement. From 2000 till 2002, he had pursued postgraduate studies in Sokoine University (Tanzania) and obtained the degree of Master in Soil Sciences and Land Management. Since 2003 till now, he is working in same research Institute (ISAR) as a researcher and head of Soil and Water Management Unit. From 1997 to date he is part time lecturer at National University of Rwanda and supervise BSc and MSc dissertations. He has long experience in consultancies in Soil Fertility and Land Management. He was admitted as a PhD student in the Land Degradation and Development Group of Wageningen University in 2006. Nsharwasi Léon Nabahungu is married and father of four children: one daughter and three sons. E-mail: nabahungu@yahoo.com.

Peer-reviewed papers

Nabahungu, N.L., and Visser, S.M. Contribution of wetland agriculture to farmer's livelihood in Rwanda. *Ecological Economics* 71: 4-12.

Nabahungu, N.L., and Visser, S.M. Farmers' knowledge and perception of agricultural wetland management in Rwanda. *Land Degradation and Development.* DOI: 10.1002/ldr.1133

Nabahungu, N.L., Mowo, J.G., Uwiragiye, A., and Nsengumuremyi, E. (2011). Use of Tithonia biomass, Maize residues and inorganic phosphate on Climbing Bean yield and Soil properties in Rwanda. Peer reviewed Book Chapter: *Innovations for a Green Revolution in Africa: Exploring the Scientific Facts*: in Bationo, A., Waswa, B.S., Okeyo, J., and Maina, F. (Eds).

Mukuralinda, A., Tenywa, J.S., Verchot, L., Obua, J., **Nabahungu, N.L.***,* and Chianu, J.N. (2010). Phosphorus uptake and Maize response to organic and inorganic fertilizer inputs in Rubona, Southern Province of Rwanda. *Agroforestry System Journal, 80, 211-221*.

Kagabo, D.M., Nsabimana, J.D., Mati, B.M., and **Nabahungu, N.L.** (2010). Performance analysis of farmer managed valley bottom irrigation system for rice production in Cyabayaga, Rwanda. In: Mati, B.M., editor. *Agricultur al Water Management delivers returns on Investment*. Compedium of 18 case studies from 6 countries in Eastern and Southern Africa. Amazon publisher.

Nabahungu, N.L., Semoka, J.M.R., and Zaongo, C. (2007). Limestone, Minjingu Phosphate Rock and Green Manure Application on Improvement of Acid Soils in Rwanda. Peer reviewed Book Chapter in Bationo A, Waswa, B.S., Kihara, J., and Kimetu (Eds). *Advances in Integrated Soil Fertility Management in Sub-saharan: Challenges and opportunities.*

Lunze, L., Kimani, P.M., Ndakidemi, P., Rabary, B., Rachier, G.O, Ugen, M.M, and **Nabahungu, N.L.** *(2002*). Selection of bean lines tolerant to low soil fertility in Africa*. BIC 4, 180-182.*

Conferences proceedings papers

Kabiligi, M., Musana, B., **Nabahungu, N.L.**, Kurothe, R.S. (2009). Increasing Productivity using rain water harvesting in Umutara semi arid zone, Rwanda. Paper presented in SSSEA (December 2009).

Mowo, J.G., **Nabahungu, N.L.**, Dusengemungu, L., and Sylver, S. (2007). Opportunities for overcoming constraints to agricultural production in Gasharu watershed, Southern province, Rwanda. In: *Sustainable Agriculture productivity for improved food security and livelihoods, Proceedings of National Conference on Agricultural Research outputs*. 26th-27th, March 2007, Serena Hotel, Kigali Rwanda.

Kayiranga, D., Mbarushimana Kagabo, D., and **Nabahungu, N.L.** (2007). Rapid apraisal of Policies & Institutional Frameworks for Agricultural Water Management, Edited by Bancy Mati. *IMAWESA Policy Study for Rwanda.*

Nabahungu, N.L., Semoka, J.R., Mowo, J.G. and Mukaralinda, A. (2006). Influence of limestone, phosphate rock and green manure on selected soil properties and nutrient uptake by maize in acidic soils. *Eastern Africa Soil Science Society.*

Nabahungu, N.L., Ruganzu, V., Mukuralinda, A., Zaongo, C., and Ntizo, S. (2005). Différentes sources du phosphore inorganique, fumier et chaux sur l'Amélioration des Sols acides du Rwanda. *African Crop conference proceedings*, Kampala, 5-9 December 2005.

Nabahungu, N.L., and Ruganzu, V. (2005). Effet du Travertin et de Tithonia diversifolia sur la Productivité du Haricot Volubile en Sols Acides du Rwanda. *PABRA Millennium Workshop.* Novotel Mount Meru, Arusha, Tanzania 28 May – 1 June 2001.

Mafuka, P.M., Futakamba, M., Gasoré, E.R., **Nabahungu, N.L.** and Hatibu, N.H. (2005). Watershed Development and Resource Management in Eastern and Central Africa: Relevance and Potential of India-Africa Knowledge. In: *Watershed Management Challenges: Improving Productivity, Resources and livelihoods*. Edited by B.R Sharma et al. pp 269-283. ISBN 92-9090-611 1

Gashabuka, N.E., Muhinyuza, B.J., Nshimiyimana, J.C., Njeru, R.W., Gasore, E.R., **Nabahungu, N.L.**, Landeo, J., Crissman, C., and Demo, P. (2005). Agronomic Potential of Advanced Late Blight Resistant Clones Developed at International Potato Center for Adaptation and Variety Selection in Rwanda. *African Crop conference proceedings*, Kampala, 5-9 December 2005. ISSN 1023-070