# Bio-economic farm modelling to analyse agricultural land productivity in Rwanda

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Jean-Claude Bidogeza

**Thesis**

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## Abstract

In Rwanda, land degradation contributes to the low and declining agricultural productivity and consequently to food insecurity. As a result of land degradation and increasing population pressure, there is urgent need to simultaneously enhance food security and agro-ecological sustainability. The main objective of this PhD thesis was to make an assessment of technology options and policy incentives that can enhance sustainable farming in Rwanda.

A multivariate analysis approach was used to clearly identify five types of farm households and their socio-economic characteristics. The main differences between the five farm types relate to gender, age, education, risk perception, risk attitude, labour availability, land tenure and income. A bio-economic model capable of analysing the impacts of soil erosion, family planning and land consolidation policies on food security in Rwanda was developed, and applied for one typical farm household. Calculations with the bio-economic model showed that a higher availability of good farm land would increase the farm income. Additionally, preserving soils against erosion and reducing risk would allow for using more marginal land which would increase food production for home consumption and for the market. Increasing the opportunities for off-farm employment can also increase farm household income. The simulation of crop yields under sustainable land management showed that predicted crop yields were distinctly higher than the actual yields for the current small-scale farming practices that are common in the region. Using the developed bio-economic model, model results showed that these sustainable agricultural technologies will clearly enhance food production (after a learning period) and income for all farm household types except the household with the largest farm for which cash at the beginning of the season is too restricted to switch to the new technologies. Provision of credit and availability off-farm activities have emerged as the most serious policies likely to affect the adoption of alternative technologies in all the farm households.

The bio-economic farm model and its applications developed in this study give more insights into the possibilities of transforming the current farming system towards more sustainable farming.

*Keywords*: Rwanda; farm household typology; sustainable technology adoption; multivariate analysis; land degradation; food security; bioeconomic model; crop simulation models; organic fertiliser; inorganic fertiliser; policy incentives.

*To my late mother, Mukakimonyo Anne-marie (1945-1992)*

## Preface

Many people have contributed to make this thesis possible. First of all, I would like to thank my supervisors: Prof. Alfons Oude Lansink, Dr. Paul Berentsen and Dr. Jan De Graaff. Thank you all for the great discussions and mentoring during these years. Alfons, I really appreciate your intellectual stimulation, professional guidance and positive attitude. Paul,

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This thesis is dedicated to my late mother, Mukakimonyo Anne-marie (1945-1992).

Jean-claude

Nairobi, May 2011.

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# Chapter 1

# General introduction

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## 1.1 Background and scope

Rwanda has one of the highest population densities in Africa. The rapid population growth is pressing on the means of subsistence such as land and water, which leads to the degradation of these resources. Furthermore, because of the population growth, almost all land is now under cultivation, which results in loss of production capacity and increasing food insecurity. There is a necessity to pursue an agricultural intensification for Rwandese farmers in the coming years to better cope with increasing demand for food. Irrigation may permit crops to be produced during the dry seasons and thus improves yields, but the development costs to implement irrigation technologies are extremely high relative to the means of small-scale farmers (Inocencio et al., 2007). Because of high investments and land fragmentation, agricultural mechanisation has been difficult to apply in Rwanda. Prices of inorganic fertilisers are beyond the financial means of small-scale farmers in Rwanda (Crawford et al., 2006). Furthermore, use of mineral fertilisers and no organic fertilisers can lead to problems such as reduction of soil fertility, soil acidification, and ground water pollution (Bekunda et al., 1997). A combined use of organic and inorganic fertilisers offers opportunities to engage in a sustainable intensification (Place et al., 2003).

The challenge of achieving economic and environmental sustainability in the face of high population pressure is overwhelming in Rwanda. There is an urgent need to simultaneously enhance food security, rural welfare and agro-ecological sustainability. This is commonly referred to as sustainable farming, i.e. agricultural technologies and practices that maximize productivity of land while minimizing damage to valued natural assets (soil, water, air and biodiversity) and to human health (Pretty and Hine, 2001). Agriculture employs almost 90% of the Rwanda's active population and generates about 45% of its GDP (Ansoms and McKay, 2010). Improving agricultural productivity is usually seen as an important means of improving food security and alleviating poverty. However, improved agricultural productivity has to be achieved in a balanced way that is not only ecologically but also economically sustainable (Peterson and Norman, 2001).

Although technical options for the sustainability of land use are available in Rwanda, yield performance remains poor and the current farming systems exhaust natural resources at a rapid pace. Despite the fact that promoted technologies (e.g. green manure, fast-growing nitrogen-fixing legumes, alley cropping) anticipate positive effects on nutrient cycling, soil protection, and crop yields (Balasubramanian and Egli, 1986; Drechsel et al., 1996; Habarurema and Steiner, 1997; Roose and Ndayizigiye, 1997, Drechsel and Reck, 1998), their adoption has remained low (Drechsel et al., 1996). Technologies promoted by agricultural research and development projects in Rwanda have not matched with the socio-economic circumstances (Raquet and Neumann, 1995). There is a tendency to assume homogeneity within the farming population, particularly with respect to socio-economic variables. Consequently, most of technology development efforts tend to favour farmers with more resources (Nkonya et al.,1997).

When emphasis is on promoting adoption of new inputs, the major concern is how to induce farmers to adopt these technologies. An appropriate policy environment is critical to transfer crop management technology (Byerlee, 1994). Lack of the right incentives leads to under exploitation of new sustainable farming technologies.

To address problems of resource depletion and to identify the right incentives to enhance farmer's adoption of more sustainable cropping practices, agro-ecological and socioeconomic approaches need to be combined (Kruseman, 2000). This can be integrated into bio-economic models (Kanellopoulos et al., 2010; Louhichi et al., 2010). Agro-ecological models are used to select feasible technologies and cropping options for specific bio-physical conditions and to assess the consequences in terms of sustainability of resources, whereas socio-economic models are able to analyse farmers' behaviour and to identify reasons for crops and technology choice. Additionally, it is argued that a functional combination of agro-ecological and economic approaches is required to provide policy-makers with adequate information about suitable incentives to induce farmers towards more sustainable land use (Ruben et al., 1998).

This study contributes to the understanding of the complex relations at farmer level between ecological and economic components of the technology choice in the context of Rwandan farming systems. The study brings insights into issues of farm income, food security, sustainability and adoption of sustainable technologies at farm level, and the possible solutions.

## 1.2 Description of the study area

Research for this study was conducted in Umutara, a former province, located in eastern part of Rwanda at 30$^{o}$ 20' eastern longitude and 1$^{o}$ 20' southern latitude with an altitude between 1,000 and 1,500 m and belonging entirely to the driest agro-climatic region in Rwanda. The choice of the province was based on the availability of data, especially with regards to biophysical data. The province has a border with Uganda in the North and Tanzania in the Southeast. Inside the country, Umutara has a border with the provinces of Byumba in the West, Kibungo in the South and Kigali-Rural in the Southwest. The province is home to the biggest National Park of Rwanda, Akagera park.

The population of Umutara was about 420,000 people in 2006 living on an area of 4,312 km$^2$. The majority of the population is newly settled with many Rwandan refugees having arrived from Tanzania and Uganda after the genocide which ended 1994. 98% of the population lives in the rural areas and obtains their livelihoods from agriculture.

Wealth in Umutara is a function of asset holding (especially livestock ownership), trading activities, and the number of active members in a household (Kasasa et al., 2000). Better-off households are those that have regular income from trading large quantities of goods and from large numbers of cattle (Kasasa et al., 2000). The poorer households derive the majority of their income from agricultural wages (GoR, 2007).

Umutara province faces problems due to lack of land availability and inadequately distributed land. While small-scale farmers with land areas less than 0.5 Ha are struggling to maintain food security, vast grazing plots were allocated to individuals or group of herds men (Musahara and Huggins, 2005). The unfortunate side of this is that cattle are more a sign of wealth and prestige than a source of food and income.

The climate in Umutara is characterised by annual temperature fluctuations, which are so small that the seasons are defined by their precipitation regime (Sirven et al., 1974). Although land is cropped over two seasons in a year, the annual yield remains insufficient to ensure food security. Poor-quality planting material, the lack of improved seed, and high costs of chemical fertilisers and of chemicals to fight plant pests and diseases constitute major production barriers.

The pedology of Umutara is quite diverse, notwithstanding the small size of the province. The main types of soils occurring in Umutara defined by the USDA Soil taxonomy (USDA, 1999), are: Inceptisols, Oxisols, Ultisols, Entisols, Vertisols, Histosols, Alfisols and Mollisols. Inceptisols and Oxisols appear to be the most important, with 60% of the area.

## 1.3 Objectives of the research

The pursuit for sustainable farming needs a combined approach of biophysical and social sciences to evaluate effects of sustainable technologies and policies on economic efficiency and agro-ecological sustainability. The overall goal of this study is to make an assessment of technology options and policy incentives that can enhance sustainable farming in Rwanda.

By fulfilling the above overall goal, farmers will gain more insight into the possibilities of changing farming systems towards more sustainable farming, and policy makers obtain insights into suitable policies to enhance adoption of new technologies that increase agricultural productivity. The overall goal can be divided into a number of research objectives:

i) To distinguish farm household types in the former Umutara province of Rwanda that might be expected to differ with regards to adoption of technology;

ii) To build a bio-economic farm model based on available resources, technology options, and socio-economic and bio-physical environmental aspects, and apply the model for the typical farm household in Umutara and validate the model;

iii) To determine alternative production activities under sustainable land management practices;

iv) To assess the potential impact of alternative production activities on farm income, food production and soil loss, and to assess policy incentives that could induce adoption of the alternative production activities by the respective farm households types.

Given the objectives, the study consists of four main steps that follow from the four research objectives. Figure 1.1. shows how the different steps are related. The steps are:

1. Classification of farm households, including available land, capital, family labour, technology options, on-farm and off-farm activities, conditions concerning the bio-

physical and socio economic environment, crop yields and income. Multivariate techniques such as Principal Component Analysis and Cluster Analysis are the methods that are used to obtain homogeneous groups of farms.

2. Development of a quadratic programming model at farm level and application of the model for the typical farm household. The model is built based on available resources, technology options, and socio-economical and bio-physical environmental aspects.
3. Determination of sustainable alternative production activities through crop simulation growth models with the Decision Support for Agrotechnology Transfer programme (DSSAT).
4. Farm model calculations to test the alternative production activities developed in step 3. Calculations are conducted with the model developed in step 2 for the different types of farm households. In addition, model calculations are used to analyse policy options to stimulate adoption of the new technologies by the different farm households.

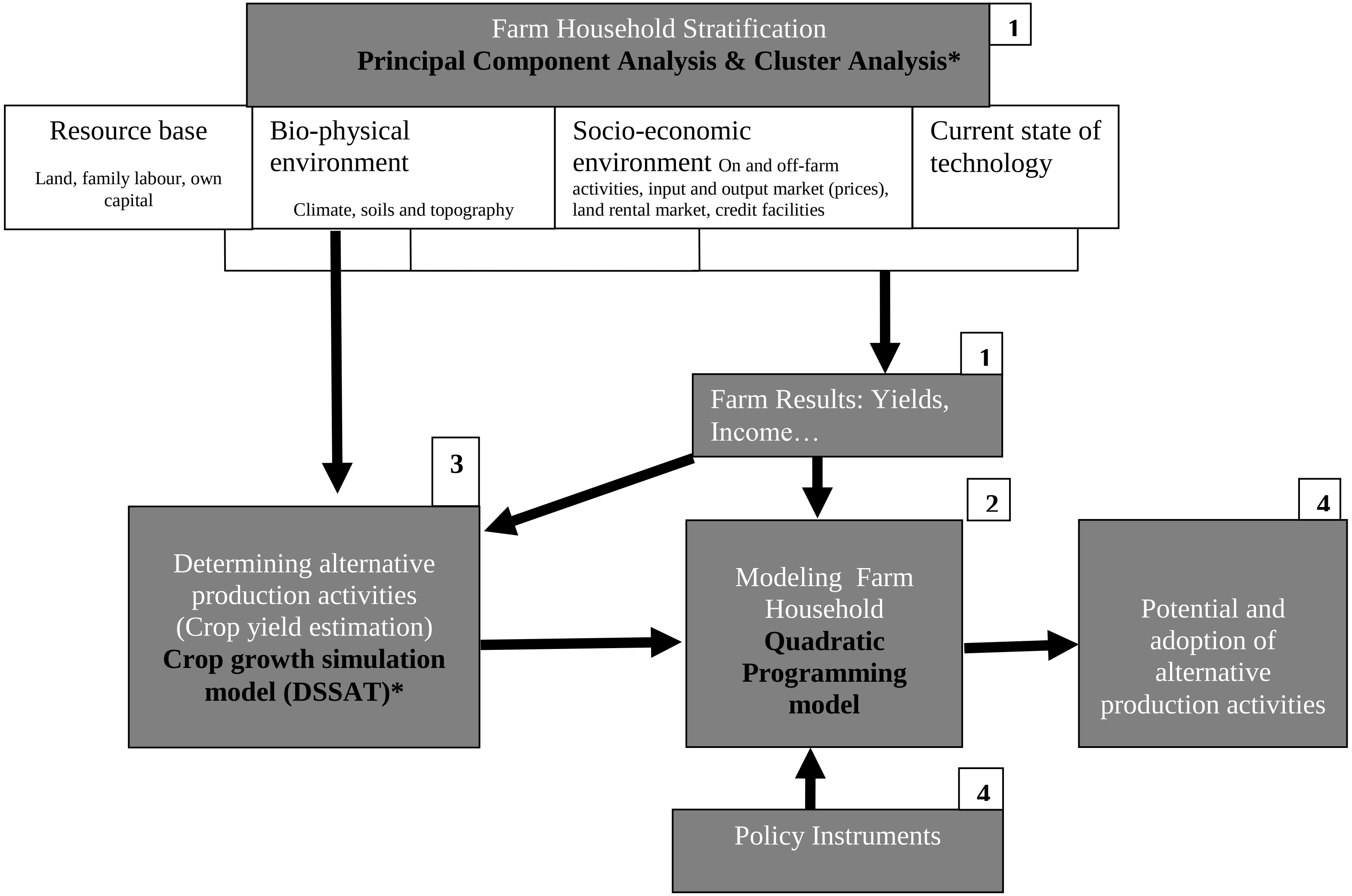


Figure 1.1. Research outline

## 1.4 Outline of the thesis

Chapter 2 starts with a literature overview of possible determinants affecting the adoption of new technologies. Next, Principal Component Analysis and Cluster Analysis are used to classify farm households based on available biophysical and farm household data.

Chapter 3 describes the quadratic programming model and applies the model for the typical farm household. The typical farm household is the average of farm types of Chapter 2. Modelling results regarding food security, technical and economic are presented. Thereafter, the results of the farm household model are compared with observed household data. The chapter ends with a model test showing the effects of family and land size on food security, farm income and soil loss.

Chapter 4 describes the Decision Support System for Agrotechnology Transfer (DSSAT). This crop growth simulation programme is used to quantify alternative production activities under combined use of organic and inorganic fertilisers. Crop yields predicted by DSSAT are discussed and compared with reported yields such as actual yields presented in chapter 2. Chapter 5 deals with farm household model calculations. The alternative production activities estimated in chapter 4 are applied in the farm household model from chapter 3 for different types of farm household derived from chapter 2. Results for the different types of farm household on food security, technical and economic results are analysed and compared. In addition, model calculations are also used to analyse policy options to stimulate adoption of new technologies. Chapter 6 discusses the methodological issues and main findings of the empirical chapters of this thesis. The chapter ends with the main conclusions from this thesis.

## Chapter 2

# A Typology of Farm Households for the Umutara Province in Rwanda

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## Abstract

*For nearly 30 years, technologies for more sustainable land use have been developed and promoted in Rwanda. However, these technologies have not been fully adopted. Keeping in mind that the farming population is not homogeneous with respect to socio-economic variables, this paper intends to typify farm households in Umutara province based on socio-economic factors influencing the adoption of new technology. A multivariate analysis approach that combines Principal Component Analysis and Cluster Analysis allowed us to clearly identify five types of farm households and their socio-economic characteristics. The main differences between the five farm types relate to gender, age, education, risk perception, risk attitude, labour availability, land tenure and income. The five farm types are characterized by respectively having a female head (26% of the farms),being a tenant (7%), having a male and literate head (32%), having an illiterate head with no off-farm activities (18%), and being a large farm with livestock (17%). The respective farm types appeared to have adopted different types of sustainable technologies to a limited extent.. Female-headed households adopted the use of compost and green manure. Young male literate farmers were the only ones using chemical fertilizers. Illiterate and full-time farmers applied fallow, manure and erosion control measures to maintain soil fertility. The use of improved livestock is adopted by large farms.*

*Keywords*: Rwanda; Farm household; Farm Typology; Technology adoption; Multivariate analysis.

## 2.1 Introduction

In Rwanda, the population density has risen rapidly over the last 3 decades and is now the highest in Africa, with an average of 380 people per $km^2$ arable land. Rural densities of more than 700 people per $km^2$ are no exception (Service National de Recensement, 2005). Sustainable use of natural resources in the face of high population density is critically important, and, consequently, food insecurity is overwhelming for Rwanda. The increasing population pressure on land and water resources leads to the degradation of these resources, which often results in the loss of productive capacity and food insecurity. Rwanda's farmers have responded to land use pressure and the associated decline in productivity by expanding into the fragile bottomlands and steep slopes. This situation has led to the excessive exploitation of natural resources and increased soil loss due to erosion, and, along with it, declining soil fertility. Research conducted by Stoorvogel and Smaling (1990) revealed that Rwanda has one of the most severe nutrient depletion rates in Africa, with on average -54 kg N, -20 kg$P_2O_5$, and -56 kg $K_2O$ $ha^{-1}$ $year^{-1}$. Furthermore, the use of mineral fertilisers is very low (0.4-0.5 kg arable $ha^{-1}$) due to the high price of fertilisers, which is aggravated by the land-locked position of the country and the associated high transportation costs (Drechsel and Reck 1998). Since fertilizer use has hardly increased in the past 20 years (GoR, 2002a) the figures on nutrient depletion of Stoorvogel and Smaling (1990) will still be valid.

For nearly 30 years, research has focused on the development and promotion of low-cost technology, such as agroforestry, fast-growing nitrogen-fixing legumes, the inter-or relay-cropping of green manure, farmyard manure, composting, mulching systems and green manure combined with other fertilisers (Drechsel et al., 1996; Roose and Ndayizigiye, 1997; Drechsel and Reck, 1998). However, despite the positive effects of these technologies on nutrient supply, a reduction in soil loss, and an increase in crop yields, fodder and firewood production, their adoption has remained low (Drechsel et al., 1996). Raquet and Neumann (1995) concluded that according to the experiences of "Projet agro-pastoral" in southern Rwanda, the adoption of new technologies, such as green manure, to improve soil fertility has failed, presumably because new technologies have not matched the socio-economic circumstances of farm households. There is a tendency to assume homogeneity within the farming population, particularly with respect to socio-economic variables (Nkonya et al., 1997). So far, no study has been undertaken in order to analyse the level of homogeneity of farm households from the perspective of new technology adoption.

It is known that the adoption of new technology may vary among farm households because of differences in socio-economic characteristics (De Graaff, 1996; Leeson et al., 1999; Solano et al., 2000; Mahapatra and Mitchell, 2001; Asfaw and Adamassie, 2004; Somda et al., 2005; Milán et al., 2006). A farm typology study can be used to classify farm households based on socio-economic characteristics that can affect the adoption of new technology. Developing a typology constitutes an essential step in any realistic evaluation of the constraints and opportunities that exist within farm households (Timothy, 1993). Typology studies can therefore be of great importance for exploring the factors that explain the adoption of new technology (Kostrowicki, 1977; Mahapatra and Mitchell, 2001). Multivariate statistical techniques allow us to create such typologies, particularly when an in-depth database is available. The combination of Principal Component Analysis for necessary reduction of the number of variables followed by Cluster Analysis to identify farm households types has been applied before by Gebauer (1987), Jolly (1988), Hardiman et al. (1990), Solano et al. (2001), Köbrich et al. (2003), Usai et al. (2006), and Jansen et al. (2006). Both methods have proven to be useful but they have their drawbacks. Principal component Analysis leads to loss of information (Jollife, 1986; Lattin et al., 2005) and Cluster Analysis has the difficulty of choosing the proper number of clusters (Alfenderfer and Blashfield, 1984; Everitt, 1993).

The objective of this paper is to distinguish several farm types that might be expected to exhibit a different behaviour with regards to technology adoption based on socio-economic variables in the former Umutara province. The focus of study is on socio-economic factors since socio-cultural factors seem to vary less as most of the farm households have a similar socio-cultural background. The different types of farm households identified will yield key information needed to understand and diagnose problems as well as identify opportunities for change with regards to the adoption of new technology. Moreover, the resulting farm types can be used subsequently in further research as a basis to build representative mathematical programming models like was done by Köbrich et al. (2003). For the purpose of this study, a new technology includes any agricultural practice or input that may increase productivity directly or indirectly and that was not yet generally used in the area of study.

The paper is structured as follows. Section 2 gives an overview of the determinants affecting the adoption of new technologies. Section 3 presents the materials and methods used, and section 4 includes the results. The last section discusses conclusions.

## 2.2. Determinants of new technology adoption: A review of the literature

The literature on the adoption of new technology is extensive and complex. Since the classic work of Griliches (1957) on the adoption of hybrid corn in the US, efforts to assess the determinants of new technology adoption have continued. Two major groups of paradigms have emerged to explain differences in technology adoption: the economic paradigm and the innovation-diffusion paradigm. The economic paradigm posits that the asymmetrical distribution of resource endowments between farmers is the major determinant of differences in adoption behaviour (Adesina and Zinnah, 1993). Upadhyay et al. (2003) distinguish two models within the economic paradigm, namely, the income and the utility models. The income model assumes that farmers are profit maximisers and that technology that increases net returns to farming firms will be adopted (Griliches, 1957; Mansfield, 1961). The strength of this approach lies in understanding the role played by one of the major factors that motivate or inhibit new technology, for instance, an increase in income. However, one of the major criticisms of this model is that it fails to recognise heterogeneity among farmer preferences (Nowak, 1987). The utility model asserts that producers make adoption decisions based on utility maximisation rather than profit maximisation (Caviglia and Khan, 2001). In this model, the producer responds to economic factors, such as income, as well as to non-economic factors, such as environmental quality and social benefits.

Many sociologists favour the innovation-diffusion paradigm and follow the earlier work of Rogers (1962), which has resulted in various concepts, including innovators (that is, early adopters), followers, and laggards. A farm household typology might help to recognise these different groups. This paradigm underlines the role of information, risk factors and the social position of the decision maker in the community. Suitability of technology is taken as a given, and the problem of technology adoption is reduced to communicating information on technology to the potential end users (Ruttan, 1996).

There have been many studies which have examined the factors influencing adoption of technology by farm households in the light of the economic and the innovation-diffusion paradigms. Especially in less developed countries (LDCs), the adoption of new technology in agriculture has attracted considerable attention from economists because the majority of the population derives its livelihood from agricultural production, and new technology seems to offer an opportunity to substantially increase production and income (Feder et al., 1985;

IFAD, 2006). Literature on technology adoption has frequently stressed the role of different factors, such as farm size, capital and labour availability (economic paradigm); education, risk perception and risk attitude, and land ownership (innovation-diffusion paradigm). The remainder of this section elaborates on these variables.

### 2.2.1. Farm size

Empirical studies have consistently showed farm size (that is, land area) to be significantly related to the adoption of new technology (Feder et al., 1985; Feder and Umali, 1993; Nkonya et al., 1997). A relatively small farm size impedes an efficient utilisation and adoption of certain types of irrigation equipment, such as pumps and tube wells (Pomp, 1998). Nkonya et al. (1997) have demonstrated that farm size significantly and positively influences the adoption of improved maize seed in a study conducted in northern Tanzania. Jamison and Lau (1982) have established a positive relation between the adoption of fertilisers and farm size in a study on Thai farmers. However, there seems to be a limit to the positive relation between farm size and technology adoption. Sureshwaran et al. (1996) found that the adoption of soil improvement measures on upland farms in the Philippines increased with farm size up to one hectare, after which size was no longer significant.

Farm size can have different effects on the rate of adoption, depending on the characteristics of the technology and the institutional setting. If technology is subject to economies of scale, then large farmers have more profit to make of a new innovation than small farmers. Several theoretical models on technology adoption reviewed by Feder et al. (1985) have revealed that high fixed costs reduce the tendency towards adoption of small farms, while large farms are identified as earlier adopters, as they have more flexibility in their decision-making, greater access to discretionary resources, more opportunities to test new technology and an enhanced ability to bear risks associated with early technology adoption (Nowak, 1987; Nkonya et al., 1997; Amsalu and De Graaff, 2007). Feder and O'Mara (1982) have noted that, in certain contexts, there may be a lower limit on farm size such that farms smaller than a certain threshold will not adopt a new technology.

### 2.2.2. Education

Empirical evidence suggests a positive relation between education and the adoption of new technology (Ervin and Ervin, 1982; Feder and Umali, 1993; Mahapatra and Mitchell, 2001; Asfaw and Adamassie, 2004; Tenge et al., 2004; Onu, 2006; Rahman, 2007). According to a review by Asfaw and Adamassie (2004), fertiliser adoption is influenced more by institutional and educational factors than by economic ones. Moreover, in a study conducted in Ethiopia Asfaw and Adamassie (2004) found that education is positively and significantly related to the use of improved wheat(varieties) but not significantly related to the probability of adopting improved wheat. Feder and Slade (1984) found that a household head's number of school years as well as his or her score on a numeracy test were key variables in enhancing the ability of farmers to acquire information and, hence, adopt new technology. Jamison and Moock (1984) found that the adoption of chemical fertiliser is positively correlated with number of school years of the head of household in Nepal. This is consistent with the work conduced in the highlands of Tanzania by Tenge et al. (2004), who found that 60% of heads of households with a secondary school education adopted soil and water conservation (SWC) measures as compared to only 23% of heads with no formal education. The model developed by Asfaw and Adamassie (2004) suggests that the educational level of other adult household members has a stronger impact on fertiliser adoption than the educational level of the head of household.  Therefore, the education of other household members should also be considered.

There is consensus that the accumulation of knowledge via education is an important factor for economic development (Asfaw and Adamassie, 2004). Educated people are expected to perform certain jobs and functions with higher efficiency and are also more likely to adopt new technologies in a short period of time (Jamison and Moock, 1984; Upadhyay et al, 2003). Adoption studies have taken education as an important explanatory factor in household decision-making.

### 2.2.3. Risk perception and risk attitude

The scarcity of empirical studies on the relation between risk and the adoption of new technology is due to difficulties in measuring and observing risk and uncertainty (Feder et al., 1985; Marra et al., 2003). Attempts to empirically investigate the roles of risk and uncertainty in adoption have been reviewed so far by Feder et al. (1985), Feder and Umali (1993) and Marra et al. (2003).

Gafsi and Roe (1979) have shown that in Tunisia, new domestically-developed crop varieties are received more favourably by farmers than unfamiliar imported varieties. A related hypothesis is that exposure to appropriate information through various communication channels reduces subjective uncertainty, as illustrated by O'Mara (1990) with regards to the effect of perceived risk regarding new varieties of grains on the adoption decisions of Mexican farmers. Feder and Umali (1993) underlined that risk-aversion leads a decision maker to diversify to reduce income risk, particularly in the absence of economies of scale with respect to the area allocated to the new technology. Kebede et al. (1990) found a positive but non-significant effect of risk-aversion for Ethiopian farmers with regards to the adoption of pesticide technology and fertiliser technology, which may be due to rainfall irregularities or other unexplained factors.

Risk has been considered a major factor that determines the rate of new technology adoption (Feder et al., 1985; Kebede et al., 1990; Baidu-Forson, 1999; Ghadim and Pannel, 1999; Marra et al. 2003). New technology in most cases involves risks, as crop yields are more uncertain with an unfamiliar technology. Risk perception is an endogenous factor, and thus, the implications of risk in terms of farmer decisions may change if the perceptions of farmers change (Feder and O'Mara, 1982). Perceptions of risk related to new technology diminish over time through the acquisition of experience and information (Feder and Umali ,1993). A farmer's attitude towards risk and his/her perception of risk on the profitability of new technologies all influence adoption decisions (Ghadim and Pannel, 1999).

### 2.2.4. Capital availability

The shortage of capital required to finance new agricultural technologies is a major constraint in the adoption of such technologies (Feder et al., 1985; Feder and Umali, 1993; Mahapatra and Mitchell, 2001). Capital can originate from a farmer's savings or from his/her credit (Feder et al., 1990).

Lack of access to cash or credit may constrain farmers from adopting technologies that require initial investments (Doss, 2006). Sources of credit may include monetary institutions (either formal or informal), relatives, friends, and rich farmers. However, in many rural areas, credit markets do not function properly (Feder et al., 1990), thereby resulting in a lack of credit. However, it has also been argued that this lack of credit alone does not inhibit the adoption of new technology that is scale-neutral. The profitability of high-yielding crop varieties (HYVs) will induce even small farmers to mobilise the relatively small cash requirements for necessary inputs. Other studies have found that a lack of credit does significantly limit the adoption of HYV technology, even where fixed costs are not high. Off-farm income sources may be viewed as an alternative to overcome cash or credit constraints, since they enable farmers to invest in new technology.

### 2.2.5. Labour availability

Shortages of family labour have been used to explain the non-adoption of HYVs in India; meanwhile, the higher rural labour supply has been associated with greater levels of adoption of labour-intensive rice varieties in Taiwan (Bos, 1998). For example, ox cultivation technology is labour-saving, and thus, its adoption might be encouraged by labour shortage. However, HYV technology generally requires more labour inputs, and so labour shortages may prevent adoption.

Labour availability is another oft-mentioned variable affecting farmer decisions about adoption of new agricultural practices or inputs (Feder et al., 1985). Some new technologies are relatively labour-saving, while others are labour-intensive (Feder et al. ,1985; Doss, 2006). For example, a shortage of labour was found to be a constraint in the adoption of agroforestry in Java and Nigeria, while in Mexico, a serious shortage of labour motivated landowners to adopt new technologies (Van der Poel and Van Dijk, 1987; Francis and Atta-Karah, 1989). When local labour markets are functioning properly, farmers can hire labour as needed. When these markets are not functional, households must supply their own labour for farm activities, and so they may choose not to adopt technologies that would require more labour at any specific time than the household can provide. Therefore, a farm household with a large number of active members is more likely to be in a position to test and then adopt potentially profitable new technology (Kebede et al.,1990; Ghadim and Pannel, 1999).

### 2.2.6. Land ownership

Many empirical studies have focused on the link between land ownership and access to credit, as ownership of land is often thought to be a prerequisite for obtaining credit. In Ethiopia, farmers must own at least 0.5 ha of maize fields to participate in the maize credit scheme

(Doss, 2006). Feder and Nishio (1999) have clearly established the difference in economic performance between titled and untitled farmers. Per unit of used land, titled farmers invest more in land, use more inputs and generate higher levels of output than untitled farmers. It is generally held that tenants of farmland are less likely to invest in conservation practices (Feder and Umali, 1993). Tenge et al. (2004) have found that households with borrowed and rented land do not apply any SWC measures to their fields. However, Lee and Stewart (1983) found that tenants are more likely to use conservation tillage than full owners. In northern of Honduras, Neill and Lee (2001) have demonstrated that land ownership increases the likelihood of using soil protection measures in general and that land security is positively and significantly associated with hedgerow adoption in particular. Sakurai (2006) has shown that investment in water supply canals for rice cultivation is influenced by the security of land tenure in western Africa .

Several studies have argued that tenure arrangement may play an important role in adoption decisions, but the subject remains riddled with considerable controversy (Feder et al., 1985; Neill and Lee, 2001). The literature distinguishes two types of land use by farmers, namely, formal entitling or various informal usufructuary arrangements (Neill and Lee, 2001). Land registration has been shown to enhance tenure security, and land titles improve economic performance mostly by facilitating access to institutional credit (Feder and Nishio ,1999). Furthermore, in the Imo State in Nigeria, insecurity in land tenure increases the risks for farmers and, therefore, may decrease their adoption of new technologies (Onu, 2005).

## 2.3. Materials and methods

### 2.3.1. Area of study

Research for this study was conducted in Umutara, a former province, located in the northeast of Rwanda at 30° 20’ eastern longitude and 1° 20’ southern latitude with an altitude between 1,000 and 1,500 m (Figure 2.1.) and belonging almost entirely to the driest agro-climatic region in the country. Annual rainfall in the province ranges from 800 – 1,000 mm with a bimodal rainfall distribution. The temperature doesn’t vary much throughout the year with an average of 20.0°C. Umutara has an area of 4,312 km$^2$.

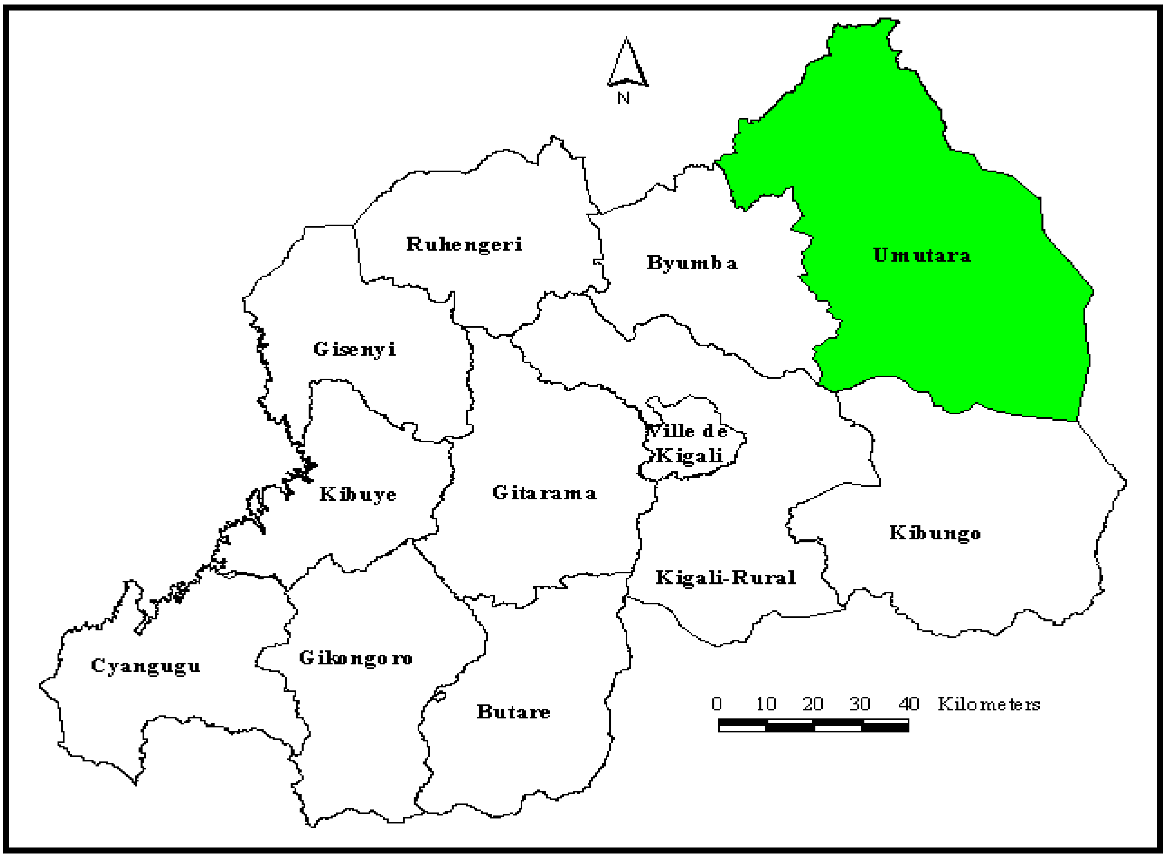


Figure 2.1. Location of the Umutara province in Rwanda.

Umutara has some 420,000 inhabitants of which 98% live in rural areas. Most of the population of Umutara is newly settled. After the genocide ended in 1994, many Rwandan refugees that had left in 1959 and 1973, after earlier clashes, returned from Tanzania and

Uganda. They brought herds of cattle with them, as Umutara was chosen for resettlement because of the abundance of potential grazing land. Many of these former refugees maintained trade links with acquaintances in neighbouring former host countries. In the context of Umutara, a household is principally defined as a nuclear family consisting of father, mother and children. In some households, relatives, particularly orphans who lost their parents during the genocide or from HIV, have been adopted into nuclear families. A study conducted by Mowo et al. ( 2006) in a small traditional area within Umutara reports an average size of household of 7 persons. Land holdings per household range from 0.25 to 2.0 ha. Land is generally owned by the farmer, while after his death, the widow becomes the land owner.

The main source of income is the sale of crop and livestock products. Additional sources include, craft work, construction and masonry, and casual labour to other farmers. Informal trade is an important source of income for the farm household. Household spend income on medical services, self-sustenance, clothing and leisure. The expenditures on leisure are higher for men than for women. A wide range of crops is grown mainly for subsistence purposes. Mixed cropping is common. The choice of crops is dictated by climatic conditions, the availability of market outlets and the ease of crop management. Maize, beans, cassava, and bananas are the most important crops. The use of inorganic fertilisers is rare due to their limited availability and high prices. Because of the importance of animal husbandry in the area, organic manure is used to a large extent to fertilise various crops (Mowo et al., 2006).

### 2.3.2. Data collection

In 2004 and 2005, data were collected in the Umutara province by the National Institute of Statistics of Rwanda using a national agricultural farm survey conducted. The farm survey covered two rainy seasons, the first season falling in the year 2004 (July-December) and the second one in the year 2005 (January – June). For the purpose of the survey, Umutara was divided into eight census zones (zones de dénombrement), with 12 farm households randomly selected in each zone. Household-level data on the 96 households were then recorded using a structured questionnaire. Both qualitative and quantitative information was collected on a total of 100 variables, including socio-economic characteristics, farm characteristics, resource availability and technological options. In addition, a small survey was conducted in 2006 using informal interviews on the characteristics of farm households, new technology adoption, production orientation, access to markets and credit, price formation, and major constraints to farming. This latter survey provided more details and background information about farming in the region and it supports the results from the national farm survey (Bidogeza, 2007).

On the basis of the review of the major factors influencing adoption of new technology (section 2), 23 variables were selected to construct a typology of farm households. The descriptive statistics of these variables are shown in Table 2.1.

Farm size (ha) is considered to be one of the most important factors in the adoption of new technologies. Households with small holdings may cultivate land more intensively to meet subsistence needs. Large farms may have a greater capacity to adopt new technology. Education is expressed in three variables, i.e., literacy of the head of household, education level of the head of household and the number of educated household members who have completed primary school. Literacy indicates the ability to write and to read, while level of education indicates whether primary school has been completed. Off-farm activities and crops per season are considered proxies for the risk perceptions and risk attitude of farm households. Off-farm activities may be viewed as a way to avoid risk and uncertainty associated with farming, while risk-averse farmers have a tendency to plant more crops to reduce risk. The source of income is expressed in terms of returns from crop and livestock and the number of household members working off of the farm. Cash is required for initial investments in many new agricultural technologies. Labour availability is expressed in the number of on-farm household members.

The ownership variable distinguishes between farm households that own land and those that rent land. For a household, being headed by a male versus a female might affect the adoption of new technology, as female-headed households have limited access to information on new technology and to other resources due to traditional social barriers (Tenge et al., 2004).

Table 2.1. Descriptive statistics (mean and standard deviation) of the variables used in principal component analysis.

| Name of variable | Description and units | Mean | Std. Deviation |
|---|---|---|---|
| *Farm size* | | | |
| Farm size | = Farm size in ha | 1.73 | 3.29 |
| *Education* | | | |
| Literacy of the head of Household | =1 if literate, 0 otherwise | .54 | .50 |
| Level of education of the head of household | =1 if finished at least primary, 0 otherwise | .25 | .43 |
| Educated family Member | = Number of educated household members | .80 | 1.04 |
| *Risk perception and risk attitude* | | | |
| Off-farm activity | =1 if head participates in off-farm activity, 0 otherwise | .55 | .49 |
| Crops per season | =Number of average crops per season | 5.64 | 1.85 |
| *Income* | | | |
| Returns per hectare | =Total returns (crops & livestock) per hectare in thousands of Rwandese francs | 566.79 | 1266.05 |
| Off-farm member | = Number of off-farm household members working outside of the farms | .79 | 1.00 |
| *Labour Availability* | | | |
| On-farm member | = Number of on-farm household members working on the farms | 2.20 | 1.06 |
| *Land Ownership* | | | |
| Ownership | =1 ownership, 0 if otherwise | .93 | .24 |
| *Personal attributes of Head of Household* | | | |
| Gender | =1 if HH is male, 0 otherwise | .66 | .47 |
| Age | =Farmer' age in years | 43.34 | 16.91 |
| Family size | =Number of household members | 4.8 | 2.36 |
| *Technological Attributes* | | | |
| Fallow | =1 if applying, 0 otherwise | .43 | .49 |
| Manure | =1 if applying, 0 otherwise | .31 | .46 |
| Compost | =1 if applying, 0 otherwise | .30 | .46 |
| Green manure | =1 if applying, 0 otherwise | .32 | .47 |
| Mulching | =1 if applying, 0 otherwise | .28 | .45 |
| Improved seed | = Quantity of improved seed in kilograms | 2.8 | 11.36 |
| Fertilisers | = Quantity of Chemical fertiliser in kilograms or litres | .21 | 1.57 |
| Pesticides | =Quantity of pesticide in kilogram or litre | .64 | 2.73 |
| Improved livestock | =Number of improved livestock | .23 | 1.58 |
| Soil and water conservation measures | =1 if Applying SWC, 0 otherwise | .35 | .48 |

The age of the household head might affect the adoption of new technology, as young people have a long time horizon, which positively impacts investments in new technology, while older farmers with a lengthy experience in farming might be conservative, thereby favouring the continuation of traditional ways. Family size may positively affect adoption decisions by releasing labour needed for farming. Large family size may encourage investments in new technology to produce enough food. Moreover, family size may affect the family income generated in off-farm work. However, large farm households may also be more risk averse (Oude Lansink et al., 2001), as they may have more dependent members, including young children and/or physically disabled individuals.

The technologies considered in this study may be grouped into two categories. The first category includes technologies with low initial investment costs, such as fallow, manure, compost, green manure and mulching. These are coded as dummy variables that get a value 1 if the particular technology is applied by the farm household and 0 if it is not applied (Table 2.1.). The selection of these technologies is motivated by their affordability and capacity to sustain the land use. In light of declining yields and a lack of alternatives, Rwanda farmers still consider these technologies as an option, especially for small farm households (Fleskens, 2005). The second category includes technologies with high initial investment costs, such as improved crop varieties, mineral fertiliser, SWC measures, and improved livestock.

### 2.3.3. Multivariate statistical analysis

Farm household data were analysed, and farm household typologies were constructed, using sequentially two multivariate statistical techniques, respectively Principal Component Analysis (PCA) and Cluster Analysis (CA). PCA condenses all the information from the original interdependent variables to a smaller set of independent variables. Reduction of variables is a necessary first step as CA cannot deal with a number of variables as high as in Table 2.1. (Jolliffe, 1986; Lewis-Beck, 1993).

Prior to PCA, the dataset was checked for appropriateness for using PCA. If the variables are largely independent or correlate very strongly, PCA may not be appropriate. Hence, the Kaiser-Maier-Olkin test (KMO) and Bartlett's sphericity test were performed to address this question (Lattin et al., 2005; Field, 2005).

Variables selected were used to construct factors using PCA. Factors were rotated using orthogonal rotation (varimax method), whereby the method tries to load a smaller number of highly-correlated variables onto each factor, resulting in easier interpretation. (Field, 2005). In accordance with Kaiser's criterion, all factors exceeding an eigenvalue of one were retained. Kaiser's criterion is accurate when the number of variables is less than 30 (Field 2005), which is the case for our data set. This approach should allow a large part of the total information to be concentrated in a small number of uncorrelated variables.

Next, factors retained from PCA were used in CA. CA seeks to typify entities (that is, farm households) *M = (M1, M2, M3…)* according to their (dis)similarity in terms of their attributes represented by selected variables N = (*N1*, *N2*, *N3*…) (Alfenderfer and Blashfield, 1984; Gebauer, 1987; Everitt, 1993*)*. Entities within a certain group or cluster should be very similar to each other, and entities belonging to different classes should be very dissimilar.

As no single objective procedure is available to determine the most suitable number of clusters, two clustering methods were used in order to ensure the stability of clusters, that is, the hierarchical method and the partitioning method (Hair et al., 2006). In the hierarchical method, the *k*-cluster solution is formed by joining together two clusters from the *k*+1 cluster solution, while the partitioning method separates the observations into a given number of clusters (Lattin et al., 2005 ).

Retained factors from PCA were used in CA using Ward's hierarchical procedure ( Alfenderfer and Blashfield, 1984). Ward's method minimises the variance within clusters and tends to find clusters of relatively equal sizes (Kobrich et al., 2003). The numbers of clusters retained from Ward's method were used as starting values in the partitioning clustering method, that is, the K-means method; accordingly, the number of clusters that seemed most realistic and meaningful was chosen for the final solution. Information from the dendogram, which results from the Ward's method, and expert knowledge of farming in the area (GoR, 2002b). were employed to select an optimal number of clusters. A dendogram is a graphical representation of the hierarchy of nested cluster solutions. In addition to CA, a one-way analysis of variance test (that is, Levene's test) was performed. The test allows us to identify the differences in variance between clusters (Field, 2005). Thus, the variables that bring about the largest differences between clusters could be identified.

## 2.4. Results and Discussion

The KMO test and the Bartlett sphericity test were performed to check whether the dataset of 96 farm households and 23 variables could be factored. Results from both tests show that the overall KMO test is greater than 0.5, which is the lower threshold (0.545), while Bartlett's sphericity test is highly significant ($p<0.001$). Hence, the variables under study are related, justifying some form of factoring.

### 2.4.1. Principal Component Analysis results

In total, 23 variables were included in PCA (Table 2.1.), of which 9 principal components with eigenvalues greater than 1 have been retained for further analysis (Table 2.2.). These 9 variables explain 72% of the total variability. Looking at each column of Table 2.2., it is possible to define each component according to the variables with which it is most strongly associated. To make it easier to identify relatively large loadings, correlations above 0.4 are in bold.

Table 2.2. Nine components resulting from principal component analysis with loadings for each of the 23 variables with cumulative variance explained.

| Name of Variables | Component | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 |
| *Farm size* | | | | | | | | | |
| Farm size | -.109 | .092 | -.206 | .348 | -.077 | **.640** | -.163 | -.068 | .200 |
| *Education* | | | | | | | | | |
| Literacy of the head | **.736** | -.243 | -.098 | .095 | .229 | .058 | .266 | .060 | -.149 |
| Level of education of the head | **.846** | .046 | -.030 | .077 | .049 | -.176 | -.098 | .001 | .103 |
| Educated family member | **.645** | **.595** | -.072 | .029 | -.177 | .022 | .021 | .027 | -.021 |
| *Risk perception and risk attitude* | | | | | | | | | |
| Off-farm activity | .108 | -.115 | .073 | **.843** | .076 | .101 | -.013 | .008 | .018 |
| Crops per season | .099 | .088 | .013 | -.006 | .151 | **-.634** | **.502** | -.162 | .151 |
| *Income* | | | | | | | | | |
| Returns per hectare | -.034 | .011 | **.940** | .041 | -.028 | -.020 | -.023 | .064 | -.070 |
| Off-farm member | .169 | .290 | .210 | **.738** | -.040 | .133 | .032 | .172 | .021 |
| *Labour availability* | | | | | | | | | |
| On-farm member | -.087 | **.832** | .027 | .009 | .211 | -.073 | .028 | .075 | .059 |
| *Land ownership* | | | | | | | | | |
| Ownership | .071 | .021 | .011 | -.044 | .000 | .114 | -.004 | .088 | **.832** |
| *Personal attributes of head of household* | | | | | | | | | |
| Gender | .177 | .018 | -.212 | .189 | **.729** | .031 | .059 | .052 | .191 |
| Age | -.311 | .449 | -.072 | -.191 | **-.559** | .061 | -.168 | .131 | .067 |
| Family size | .093 | **.826** | .050 | .091 | -.049 | .323 | .042 | -.001 | -.013 |
| *Technological attributes* | | | | | | | | | |
| Fallow | .162 | .065 | .020 | -.189 | .133 | .041 | **.756** | -.169 | -.051 |
| Manure | -.245 | .062 | .063 | -.202 | .101 | .057 | .371 | **.525** | .262 |
| Compost | .239 | -.002 | .307 | -.444 | -.396 | -.051 | -.013 | .173 | .124 |
| Green manure | .185 | -.043 | .015 | -.362 | -.189 | .104 | -.128 | .459 | **-.537** |
| Mulching | .432 | .189 | .149 | -.034 | -.141 | -.261 | -.103 | **.501** | .144 |
| Improved seed | .052 | .029 | .074 | .194 | .138 | -.018 | -.050 | **.745** | -.060 |
| Fertilisers | -.066 | .028 | **.923** | .110 | .015 | -.036 | -.006 | .071 | .075 |
| Pesticides | -.120 | -.049 | -.073 | .286 | -.091 | -.081 | **.665** | .195 | .045 |
| Improved livestock | -.045 | .167 | .053 | .030 | .112 | **.726** | .148 | -.071 | .064 |
| Soil and water conservation measures | -.133 | .216 | .224 | -.213 | **.728** | -.011 | -.011 | .198 | -.059 |
| Eigenvalues | 2.77 | 2.57 | 2.44 | 2.09 | 1.88 | 1.37 | 1.19 | 1.11 | 1.03 |
| Cumulative explained variance | 12% | 23% | 34% | 43% | 51% | 57% | 62% | 67% | 72% |

N.B. Bold numbers refer to loadings high than 0.5

The first component (F1), which explains 12% of variance, is positively correlated with literacy, level of education and the number of educated family members. Thus, F1 represents the overall education level.

The second (F2) and third (F3) components are almost as important as the first component, each explaining 11% of variance. The second component is mostly related to family size, the number of educated family members and on-farm family members. This implies that farm households with large families are those that have more on-farm and educated family members. This component could be referred to as family size. The third component (F3) is strongly correlated with returns per hectare and the use of fertilisers.

Hence, the adoption of mineral fertilisers results in high returns.

The fourth (F4) and fifth components (F5) both explain 9% of variance. F4 is positively related to off-farm activities and family members off-farm. This component could be referred as to as off-farm activity. The fifth component is defined mainly by SWC measures; and the head of household gender is positively correlated, while the age of the head of household is negatively correlated with this fifth component. That is, households headed by young males are most likely to apply SWC measures.

The remaining four components each explain about 5% of variance. The sixth component (F6) shows a relationship between farm size, on the one hand, and improved livestock and the number of crops per season, on the other. Large households own improved livestock and cultivate fewer crops per season. The seventh component (F7) shows a positive correlation of pesticides with respect to the number of crops per season and fallow, while the eighth (F8) component is positively correlated with manure, mulching, and improved seed. The ninth (F9) component shows a negative relationship between land tenure and use of green manure, as tenant farm households tend to use more green manure.

### 2.4.2. Cluster Analysis results

First, the nine components were analysed using Ward's technique. The dendogram, which results from Ward's technique, illustrates the sequence in which farm households were merged into the clusters (see Figure 2.2.). The dendogram includes four cutting lines; in fact, a key issue in generating such diagrams involves where to ‘cut’ the tree in order to arrive at an appropriate number of clusters that best fits the data set. Shifting the cutting line to the right (that is, from A to B in Figure 2.2.) reduces the number of clusters to nine. A further shift to the right, i.e., towards lines C and D, creates seven and five clusters, respectively. Cutting line A creates small clusters that are generally not acceptable and should be eliminated, as the number is too small (Hair et al., 2006). Thus, the numbers of clusters provided by cutting lines B, C and D (that is, nine, seven and five clusters, respectively) were drawn from the dendogram for use in the partitioning cluster method.

The number of retained clusters to be realistic with respect to the empirical situation in order to be accepted as a meaningful classification. Following that line of reasoning, nine clusters based on the partitioning method is defined as the appropriate number of clusters, since these clusters seem to best represent farm households within the Umutara province. They contained three single clusters and one paired cluster, which were discarded, as it was considered that these farms were too different from the rest of the sample and thus could considered as outliers. Differences concerned high input levels of improved seed, fertilisers and pesticides.

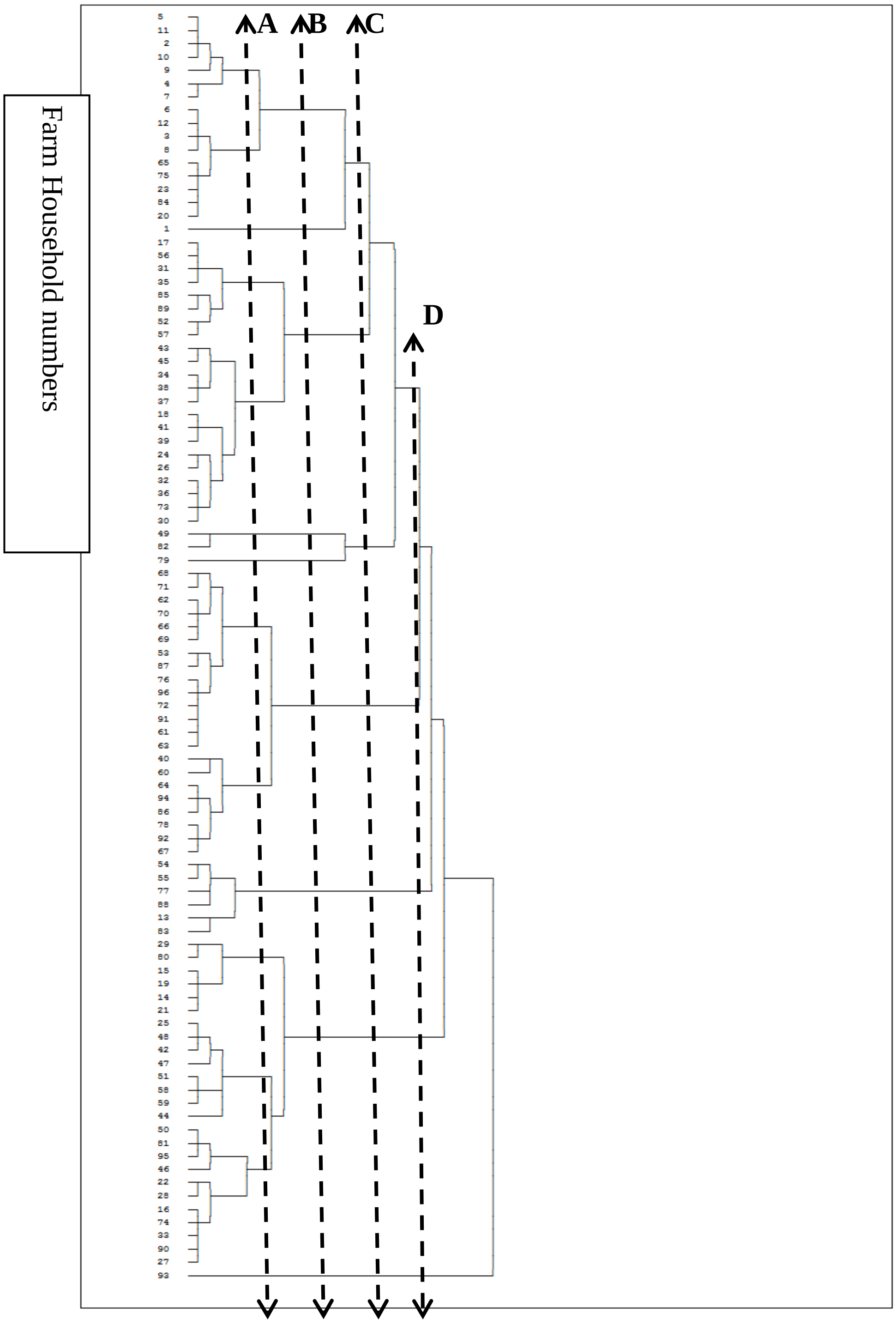


Figure 2.2. Dendogram with four possible cutting lines resulting from Wards method of cluster analysis

N.B. - Numbers on Y-axis express the Farm household identification
- Letters show the cutting lines: A gives 14 clusters, B gives 9 clusters, C gives 7 clusters and D gives 5 clusters.

The remaining five clusters appeared to represent the real situation based on information from our field work conducted from 2006. The results obtained from the five clusters are reported in Table 2.3., which shows the p-values for a one-way analysis of variance for each variable (equality of group means). The more distinct a variable value is among groups, the lower is the p-value.

Given the established typology, we ask: what are the characteristics differentiating the five clusters? Judging from the p-values (Table 2.3), factors such as gender, age, literacy, level of education, off-farm activity, number of off-farm family members, tenure and farm size seem to be significantly important in differentiating the clusters. As this also is true for all technological attributes except pesticides (Table 2.3), this indicates that appropriate variables were chosen to construct this adoption-based typology.

Cluster I, which accounts for 26% of farm households, is dissociated from the others due to it having the strongest discriminating power for the gender of the household head variable. Thus, cluster I comprises mainly households headed by females, i.e., either widows due to the genocide or to natural decease or those with husbands in prison due to suspected participation in the genocide. Furthermore, the cluster has relatively few off-farm activities but relatively high returns per hectare. In this cluster, we find above-average use of compost, green manure and improved seed. Adopting relatively cheap inputs such as compost and green manure as found in the cluster I, seems to endorse the findings of Kharwara et al. (1991) and Doss and Morris (2001), which demonstrate that constraints faced by female-headed households, such as low level of education and small farm size, prevents the adoption of costly technologies such as chemical fertiliser, which also require technical knowledge.

Table 2.3. Characteristics of selected clusters of farm households and P-value of one way analysis of variance (equality of group mean).

| | Cluster I N=24 *Female Headed* | Cluster II N=6 *Tenant* | Cluster III N=28 *Male& Literate* | Cluster IV N=17 *Illiterate & Full time* | Cluster V N=16 *Large & Livestock* | Cluster Means | Cluster Standard Deviation | P-Value |
|---|---|---|---|---|---|---|---|---|
| *Farm size* | | | | | | | | |
| Farm size | 0.53 | 0.30 | 0.75 | 0.92 | 6.43 | 1.69 | 3.34 | 0.00 |
| *Education* | | | | | | | | |
| Literacy of the Head | 0.5 | 0.66 | 0.96 | 0.11 | 0.25 | 0.53 | 0.50 | 0.00 |
| Level of Education of the Head | 0.2 | 0.16 | 0.60 | 0.00 | 0.00 | 0.25 | 0.43 | 0.00 |
| Educated family member | 0.66 | 0.66 | 1.17 | 0.52 | 0.62 | 0.79 | 1.05 | 0.44 |
| *Risk perception and risk attitude* | | | | | | | | |
| Off farm activity | 0.33 | 0.50 | 0.71 | 0.17 | 0.93 | 0.53 | 0.50 | 0.00 |
| Crops per season | 5.45 | 5.58 | 6..33 | 6.17 | 4.2 | 5.6 | 1.88 | 0.71 |
| *Source of cash* | | | | | | | | |
| Returns per hectare | 555.68 | 755.83 | 514.66 | 431.11 | 123.78 | 457.05 | 545.94 | 0.07 |
| Off farm member | 0.41 | 0.50 | 0.92 | 0.17 | 1.43 | 0.71 | 0.92 | 0.05 |
| *Labour availability* | | | | | | | | |
| On farm member | 1.5 | 1.8 | 2.1 | 3.2 | 2.2 | 2.17 | 1.07 | 0.09 |
| *Land tenure* | | | | | | | | |
| Tenure | 1 | .00 | 1 | 1 | 1 | 0.93 | 0.24 | .00 |
| *Personal attributes of Head of Household* | | | | | | | | |
| Gender | 0.16 | 0.5 | 1 | 0.8 | 0.6 | 0.65 | 0.47 | 0.00 |
| Age | 48.9 | 41.5 | 31 | 48.2 | 52.6 | 43.4 | 17.2 | 0.08 |
| Family size | 3.9 | 4 | 4.3 | 5.6 | 6.06 | 4.7 | 2.3 | 0.69 |
| *Technological Attributes* | | | | | | | | |
| Fallow | 0.5 | 0.33 | 0.5 | 0.58 | 0.06 | 0.43 | 0.49 | 0.00 |
| Manure | 0.37 | 0.16 | 0.1 | 0.58 | 0.18 | 0.28 | 0.45 | 0.00 |
| Compost | 0.66 | 0.16 | 0.14 | 0.35 | .00 | 0.29 | 0.45 | 0.00 |
| Green manure | 0.54 | 0.66 | 0.25 | 0.29 | 0.00 | 0.31 | 0.46 | 0.00 |
| Mulching | 0.29 | 0.16 | 0.39 | 0.17 | 0.12 | 0.26 | 0.44 | 0.00 |
| Improved seed | 1.87 | 0.00 | 1.5 | 0.58 | 0.00 | 1.06 | 4.17 | 0.03 |
| Fertilisers | 0.00 | 0.00 | 0.17 | 0.05 | 0.00 | 0.06 | 0.38 | 0.00 |
| Pesticides | 0.28 | 0.16 | 0.46 | 0.65 | 0.16 | 0.38 | 0.98 | 0.244 |
| Improved livestock | 0.04 | 0.00 | 0.00 | 0.00 | 0.43 | 0.08 | 0.43 | 0.00 |
| Soil and water conservation measures | 0.41 | 0.33 | 0.46 | 0.82 | 0.00 | 0.32 | 0.47 | 0.00 |

Cluster II comprises 7% of farm households. The tenure variable has high discriminating power in distinguishing cluster II from other clusters. Farm households in this cluster are landless; rather, they are land tenants. Moreover, the cluster has the smallest farm size, with an average of 0.3 ha. However, high returns and high labour use per hectare are observed in this cluster. Farm households farm intensively with a relatively high use of green manure. Green manure is an effective way of improving soil fertility, and it is a labour-intensive technology (Ndiaye and Sofranko 1994; Drechsel and Reck 1998). Thus, affordability and labour availability are reasons that farm households of this cluster adopted this technology, as the small area and the insecurity of land tenure prevent them from adopting other technologies. Overexploitation of land through high labour use and the low level of inputs (only green manure) could lead to the exhaustion of soil fertility, resulting in gradually declining returns per hectare.

For cluster III, which comprises 31% of farm households, the main distinguishing features include gender, age and education level of the household head. Farm households in this cluster are headed by young men (31 years old on average) with more education than those in other clusters. In these households, costly technologies, such as improved seeds and chemical fertilisers, have been adopted at a rate of adoption above the mean across clusters. Young, educated male households headed are more likely to adopt new technologies, especially those that require information and an effective combination of inputs. Off-farm activities are also important, but they do not distinguish cluster III from clusters I, II, and IV. This could indicate that farm households classified in cluster III have relatively more economic options, which allows them to use capital-intensive technologies.

Cluster IV, which comprises 18% of households, represents farm households with a high level of illiteracy and the quasi-absence of off-farm activities. Moreover, these farm households are characterised by a relatively high labour to land ratio as compared to clusters I, III, and IV. Farm households farm with a relatively intensive use of fallow, manure and SWC measures. Thus, illiteracy and a lack of off-farm activities as a source of additional income prevent farm households from adopting costly technologies, such as improved seed, chemical fertilisers and improved livestock. The cluster shows the highest SWC measures, which suggest that the adoption of labour-demanding technology reflects the relatively high availability of labour in this cluster.

Cluster V includes 17 % of farm households, and it is characterised by a large farm size, with an average of 6.43 ha, as well as a large number of household members working outside the farm. These farms have adopted improved livestock but almost no other technology.

It seems that farm households classified into this cluster have devoted their farm to pasturing. The returns per hectare in this cluster are lowest among all clusters; in fact, they are one-sixth of the returns per hectare of cluster II.

### 2.5. Conclusions and policy implications

A multivariate analysis approach that combines PCA and CA allows us to clearly identify five typical farm households with respect to new technology adoption using socio-economic factors within the Umutara province. The data on 23 variables from 96 farm households were evaluated by multivariate statistical methods. Principal component analysis identified 9 factors that accounted for over 72% of variance in the original 23 variables. These nine factors were used in cluster analysis to typify farm households. Results from cluster analysis lead to identification of five farm types. The first type is characterised by female-headed households with a relatively high use of compost, green manure, and improved seeds. The second type represents tenants with small farms, high returns per hectare, and a relatively high degree of labour use per hectare. These farmers intensify farming through the use of green manure. The third type represents households headed by relatively young and literate males that intensively farm using chemical fertilisers and improved seeds. The fourth type represents illiterate and full-time farmers. The technologies they use most are fallow, manure, and SWC. The fifth type represents large farms with improved livestock, which have the lowest returns per hectare. The only technology adopted within this cluster is improved livestock.

Statistical testing showed that the discriminating power of most of the variables mentioned in section 2 and of the variables representing technology use is high. This indicates that the typology constructed can be useful to explore the adoption of new technologies.

The low returns per hectare on the large farms of cluster V are in the line with several studies on Rwanda that report that some residents in the former Umutara province are acquiring land for the purpose of speculation rather than for agricultural production (Musahara and Huggins ,2005; Pottier, 2006). Given the much higher returns per hectare and the willingness to use low-cost technologies to maintain and improve soil fertility of the smaller farms, a policy to redistribute land in favour of smaller farms may address this situation.

The study has underlined the heterogeneity of farm households with regards to the current use and the determinants of future use of new technologies. As some types of farms have better possibilities for adopting technologies than others, extension messages and policies should be more focused on specific groups, like these five farm types.

From this study, it can be concluded that multivariate statistical techniques such as PCA and CA are suitable tools for identifying important socio-economic characteristics of farm household types that underlie the adoption of new technology. Differentiation of farms types should help to build mathematical programming models on the basis of one farm household, which is the next step in terms of further research.

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**Chapter 3**

# Bio-economic modelling of sustainable farm production and food security for smallholders in Rwanda

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## Abstract

*Rwandan agriculture is not able to meet its population's food needs from its own production, which results in food insecurity. Land degradation is a serious problem which contributes to a low and declining agricultural productivity and consequently to food insecurity. The objective of this paper is to develop a bio-economic model capable of analysing the impacts of soil erosion, family planning and land consolidation policies on food security in Rwanda. The results of the bio-economic model show that a higher availability of good farm land would increase the farm income. Additionally, preserving soils against erosion and reducing risk would allow for releasing more marginal land which would increase food production for home consumption and for the market. Increasing the opportunities for off-farm employment can also increase farm household income. The outcomes of the model support the Rwanda policy on family planning, while the policy on land consolidation is not endorsed.*

*Key words*: Rwanda, Land degradation, food security, bioeconomic model, family planning policy, land consolidation policy

## 3.1. Introduction

Agricultural statistics indicate that per capita food production in Rwanda is declining (Minecofin, 2003a; RADA, 2005; NISR, 2008). This trend is putting at stake the food security of the rural and urban poor. Rwandan agriculture is not able to meet its population's food needs with the national production. m

Land degradation is a serious problem which contributes to the low and declining agricultural productivity and consequently to food insecurity. Land degradation can be defined in terms of loss of actual or potential productivity as a result of natural or human factors (Anecksamphant et al., 1999). Soil erosion and soil mining are believed to be the most important causes of land degradation in Rwanda with a soil loss of 50 to 400 tons per hectare per year depending on location (Mugabo, 2005). Some slopes are totally degraded by erosion and no production is possible without restoring fertility. In addition, Rwandan soils have a very low organic matter content and weak soil fertility potential except for the marshy and volcanic soils (Gecad, 2004). Furthermore, land scarcity due to the high population density is limiting options for extending farm size. In Rwanda, the biophysical causes of land degradation are relatively well known, but less is known about the economic impact of land degradation on farming activities. Very little modelling analysis exists at farm level on the economic consequences of land degradation (Byiringiro and Reardon, 1996; Clay et al., 1998; Musahara, 2006).

Rwanda's population, which is made up mostly of subsistence farmers, has quadrupled during the last 50 years. At present, Rwanda has 9,3 million inhabitants with a density of 380 inhabitants/km$^2$. The average size of a family farm is 0.76 haa (Minagri, 2004). If the human reproduction rates are not slowing down, the population will double by 2030 (Kinzer, 2007), with dramatic consequences for natural resources and food security. Thus, it is important to balance the increasing population with the limited available land, and ensure food security.

The new land law put in place by the Rwandese government stipulates that, under its article 20, landholdings less than one hectare (ha) are deemed insufficient for effective exploitation (Minerena, 2005). Therefore, the land law and land policy tend to encourage farm households to consolidate their land, but those whose consolidated land remains under 1 hectare stand to lose it according to this law (Pottier, 2006). This ruling follows a recommendation made by the Poverty Reduction Strategy paper (Minecofin, 2003b): “households will be encouraged to consolidate plots in order to ensure that each holding is not less than 1 hectare. This will be achieved by the family cultivating in common rather than fragmenting the plot through inheritance”.

Decisions on land use are basically made by heads of farm households. As in many other developing countries, a farm household system in Rwanda concerns production (of crops and livestock), off-farm activities and consumption (of food, other basic needs and some leisure). A major characteristic is the non-separability of production and consumption decisions. The allocation of productive resources and the choice of activities could affect land degradation and subsequently food security. It is assumed that farm households are rational in pursuing certain meaningful objectives which guide their behaviour (Upton, 1996; Anderson, 2002; Woelcke, 2006; Laborte et al. 2007; Laborte et al., 2009). However, the decision-making process is restricted by the range of possible alternative activities that can be undertaken and constraints imposed by limited resources availability and other external conditions like agricultural and/or environment policies (Senthilkumar et. al, 2011).

To understand the complex relations at farm level between technical, ecological and economic components, there is a need to combine information from biophysical and social sciences (Kruseman, 2000). Bio-economic modelling is at the interface of biophysical and social sciences, enabling the accommodation of biophysical data in economic analysis (Kanellopoulos et al., 2010; Louhichi et al., 2010).

In developing countries, many studies have made use of bio-economic farm models and there is growing interest for its application (Jansen and Van Ittersum, 2007). However, little modelling analysis at farm household has been conducted in subsistence or semi-subsistence farming. Barbier (1990), Cárcamo et al. (1994), Barbier and Bergeron (1999) and Louhichi et al. (1999) evaluated the economic nature of land degradation and estimated net returns from erosion control. Van Keulen et al. (1998), Kruseman and Bade (1998), Kuyvenhoven et al. (1998), Ruben et al. (1998), Struif Bontkes and Van Keulen (2003) assessed different sustainable technologies to improve farm household income and soil fertility. Dorward (1999) investigated the conditions under which peasant farm household models may need to allow embedded risk. Anderson (2002), Mudhara et al.(2002), Thangata et al. ( 2002) examined the options for improving household food security for small-scale farms.

Modelling farm households might bring some insights into the ongoing debate on land and family planning reforms and the potential impacts of soil erosion. However, so far no modelling studies in sub-Saharan countries have incorporated at the same time soil erosion, soil fertility, soil quality and food consumption in terms of energy and proteins, risk, labour, land, cash and credit availability in their economic evaluation of crop production for farms.
The objectives of this paper are:i) to develop a general bio-economic model capable of analysing the impacts of family planning, land consolidation and soil erosion on farm production and food security in Rwanda; ii) to apply the bio-economic model for a typical farm in Rwanda.

The remainder of this paper is structured as follows. The next section describes the study area and the farm household model. Next, data and application of the model for a typical farm are presented. This typical fam household is the average of farm types distinguished in Chapter 2. This is followed by the presentation of the modelling results regarding food security, technical and economic results for the typical farm. The outcomes of the farm household model are compared with observed farm household data; and the effects of family and land size changes on food security, income and soil loss results are determined and discussed. Thereafter follow the conclusions.

## 3.2. Materials and methods

### 3.2.1. Area of study and typical farm

The area of study is in Umutara, a former province located in the eastern part of Rwanda, approximately 180 km from Kigali along the main tarmac road between Kigali and Kagitumba (border with Uganda). It has a border with two countries, Uganda in the north, and Tanzania in the southeast. The tarmac road and the geographical position of Umutara imply that the market access is fairly good.

Most inhabitants of Umutara are former refugees who arrived from Tanzania and Uganda after the genocide which ended in 1994. When they returned to Rwanda, Umutara was chosen for their resettlement. The increasing population puts a high pressure on natural resources of the province, and different land uses often compete for the same piece of land.

Umutara province belongs almost entirely to the agro-climatic zone of the Central Bugesera and the Savannahs of the East, which is the driest agro-climatic region of Rwanda. The annual precipitation is quite variable in the region and is on average lower than 1000 mm (Sirven et al., 1974). The irregularity of the precipitation is a frequently stated problem for Umutara. The climate of Umutara is bimodal (Fleskens, 2007), with two growing seasons annually. The agricultural activities for one season referred to as B last from January to June, and agricultural activities for the other season referred to as A take place from July to December.

The pedology of Umutara is quite diverse, notwithstanding that it is only a small area. Two types of soils are dominant in Umutara: Inceptisols and Oxisols (USDA, 1999), mostly located on gentle (2-6%) and moderate (6-13%) slopes, respectively. These land types are covering 60% of the total soil in Umutara province, respectively 40% for Oxisols and 20% for Inceptisols (Ghent University, 2002). The chemical fertility of Oxisols is poor; weathered minerals and cations retention by mineral soil fraction is weak, while Inceptisols have a satisfactory chemical fertility and contain at least some weathered minerals in silt and sand fraction (FAO, 2001). Despite of the low fertility of the soils, small-scale farmers maintain soil fertility and reduce soil erosion by using low input systems such as crop rotations, organic fertilisers and few of them also use some chemical fertilisers. However, these land management strategies are not suficient for a sustainable farming.

With respect to the importance of the different crops cultivated in the region: 33% of the cultivated land is occupied by cereals, followed by tubers (29%), leguminous crops (21%) and bananas (15%) (Minagri, 2002).

The farm household analysed in this paper is typical for the province. Important socio-economic variables used to characterise the typical farm household were average farm data at regional or national level derived from the literature and field survey (Kinzer, 2007; Loveridge et al., 2007; Strode et al., 2007; Bidogeza et al., 2009; Ansoms and McKay, 2010).

### 3.2.2. Model specification and data used

#### 3.2.2.1. General structure

The basic structure of the bioeconomic farm household model is shown in equation (1). It has the mathematical form of a quadratic programming model ( Hazell and Norton, 1986):

$$\text{Maximise } \{Z = c'x - \text{Ø} \sigma\} \quad (1)$$

Subject to $Ax \leq b$

and $x \geq 0$

where: Z = expected utility; c = vector of gross margins, costs or revenues per unit of activity; x = vector of activities; A = matrix of technical coefficients; b = vector of resource availabilities; Ø = risk aversion coefficient (Ø >0); σ = standard deviation of total gross margin.

The model presented here is a quadratic programming model with a time span of one year (two seasons). The expected utility is the objective function and this is maximized. The farmer is assumed to maximise expected utility which is defined as discretionary income minus the risk premium. Discretionary income is defined as income available for spending after essential expenses have been made (Castano, 2001; Laborte et al., 2009). The most important essentials include clothes, taxes, medication, school fees, kitchen ustensils and food ingredients.

Activities include crop production for home consumption, crop production for sale, off-farm activities, hiring labour, family expenditures, borrowing credit. Major constraints include land, labour in three different periods per season, rotations, available cash, maximum credit, food consumption requirements, soil loss and soil organic matter.

The major activities and constraints are summarized bythe equations (2) to (14). For the description of the indices, coefficients and variables see Tables 3.1, 3.2 and 3.3, respectively.

c'x =
$$\sum_{c,se,lu}(Y_{c,se,lu} * vL^{m}_{c,se,lu}) * Pr_{c,se} - \sum_{c,se,lu}[(Cs_{c,se,lu} * vL^{m}_{c,se,lu}) + (Cs_{c,se,lu} * vL^{c}_{c,se,lu})] - (\sum_{pe,se} vHlab_{pe,se} * Wage) + (\sum_{pe,se} vOfflab_{pe,se} * Wage) - \sum_{pe,se}(Exp_{pe,se}) - vI \quad (2)$$

The discretionary income per year is defined as returns from the sale of crops production ( $\sum_{c,se,lu}(Y_{c,se,lu} * vL^{m}_{c,se,lu}) * Pr_{c,se}$ ) plus wages from off-farm activities ($\sum_{pe,se} vOfflab_{pe,se} * Wage$ ) minus costs of seeds/establishment costs ($\sum_{c,se,lu}[(Cs_{c,se,lu} * vL^{m}_{c,se,lu}) + (Cs_{c,se,lu} * vL^{c}_{c,se,lu})]$) and costs of hired labour ($\sum_{pe,se} vHlab_{pe,se} * Wage$ ) and expenditures ($\sum_{pe,se}(Exp_{pe,se})$) and total interest ($vI$).

$$\sigma = \sqrt{\sum_{c,se,lu}[varcovar^{m}_{c,se} * (vL^{m}_{c,se,lu})^2 + varcovar^{c}_{c,se} * (vL^{c}_{c,se,lu})^2]} \quad (3)$$

The standard deviation for total gross margin is calculated from the variance/covariance matrix of gross margins for the crops per season and the area of crops per season for consumption and for marketing respectively..

*Land constraint (for each season and land type)*

$$\sum_{c}(vL^{m}_{c,se,lu} + vL^{c}_{c,se,lu}) \leq AVL_{se,lu} \quad (4)$$

*Labour constraint(for each season and each period)*

$$\sum_{c,lu}[(Labreq_{c,pe,se,lu} * vL^{m}_{c,se,lu}) + (Labreq_{c,pe,se,lu} * vL^{c}_{c,se,lu}) + vOfflab_{pe,se}] \leq vHlab_{pe,se} + AVlab_{pe,se} \quad (5)$$

$$vOfflab_{pe,se} \leq MaxOfflab_{pe,se} \quad (6)$$

*Rotations constraint (for each season and each land type)*

$$vL^{m}_{leg,se,lu} + vL^{c}_{leg,se,lu} = vL^{m}_{len,se,lu} + vL^{c}_{len,se,lu} \quad (7)$$

*Minimum food consumption constraints(for each season)*

$$\sum_{c,lu}[(Y_{c,se,lu} * vL^{c}_{c,se,lu}) * En_{c}] \geq Enreq_{se} \quad (8)$$

$$\sum_{c,lu}[(Y_{c,se,lu} * vL^{c}_{c,se,lu}) * Prot_{c}] \geq Protreq_{se} \quad (9)$$

*Cash constraints (for each season and each period)*

$$vCash_{pe,se} = vCred_{pe,se} + vOfflab_{pe,se} * Wage + \sum_{c}(Totrev_{c,se}) - vHlab_{pe,se} * Wage - Exp_{pe,se} - \sum_{c}(Totcostse_{c,se}) \quad (10)$$

*Required credit (for each season and each period)*

$$vCred_{pe,se} = vCred_{pe-1,se} * (1 + ri) - vRepay_{pe-1,se} + vNewcred_{pe,se} \quad (11)$$

*Credit constraint (for each season and period)*

$$\sum_{pe} vCred_{pe,se} \leq Credlim_{se} \quad (12)$$

*Soil loss constraint (per year for each land type)*

$$\sum_{c,se}[(Soill_{c,se,lu} * vL^{c}_{c,se,lu}) + (Soill_{c,se,lu} * vL^{m}_{c,se,lu})] \leq Soilltol_{lu} \quad (13)$$

*Soil fertility constraint (per year for each land type)*

$$\sum_{c,se}[(Soc_{c,se,lu} * vL^{c}_{c,se,lu}) + (Soc_{c,se,lu} * vL^{m}_{c,se,lu})] \leq Socav_{lu} \quad (14)$$

Table 3.1. Indices used in the farm household model

| Index | Description | Elements |
|---|---|---|
| C | Crop | Banana, beans, cassava, groundnut, maize, sorghum, sweet potato |
| Leg | Leguminous | Beans, groundnut |
| Len | Non leguminous | Cassava, maize, sorghum, sweet potato |
| Lu | Land type | Inceptisols, Oxisols |
| Pe | Period | Period 1, period 2, period 3(in each season) |
| Se | season | Season A, season B |

Table 3.2. Coefficients used in the farm household model

| Coefficient | Description | Dimension |
|---|---|---|
| AVL | Available land | ha |
| AVlab | Available labour | man-day |
| Credilim | Credit limit | fr.rw |
| Cs | Cost of seed/establishment costs | fr.rw ha$^{-1}$ |
| En | Energy content per crop | Kcal kg$^{-1}$ |
| Enreq | Energy requirement | Kcal season$^{-1}$ |
| Exp | Expenditure | fr.rw |
| Labreq | Labour requirement | man-day ha$^{-1}$ |
| MaxOfflab | Maximum off farm labour | man-day |
| Pr | Price products | fr.rw kg$^{-1}$ |
| Prot | Protein content per crop | g kg$^{-1}$ |
| Protreq | Protein requirement | g season$^{-1}$ |
| Ri | Rate of interest | % |
| Soc | Soil organic matter | t ha$^{-1}$ season$^{-1}$ |
| Socav | Soil organic matter available | t ha$^{-1}$ year$^{-1}$ |
| Soill | Soil loss | t ha$^{-1}$ season$^{-1}$ |
| Soilltol | Soil loss tolerance | t ha$^{-1}$ year$^{-1}$ |
| Totcostse | Total cost of seeds/establishment costs | fr.rw ha$^{-1}$ |
| Totrev | Total returns from crop sales | fr.rw ha$^{-1}$ |
| $Varcovar^{c}$ | Variance /covariance matrix of Gross Margins of crops for home consumption (using constant product prices) | - |
| $Varcovar^{m}$ | Variance /covariance matrix of Gross Margins of marketed crops. | - |
| Wage | Wage | fr.rw day$^{-1}$ |
| Y | Yield | Kg ha$^{-1}$ |

Table 3.3. Variables used in the farm household model

| Variable | Description | Dimension |
|---|---|---|
| vCach | Cash | fr.rw |
| *v*Cred | Credit required | fr.rw |
| *v*Hlab | Hired labour | man-day |
| *v*I | Total interest | fr.rw $year^{-1}$ |
| $vL^c$ | Land allocated to crop for consumption | ha |
| $vL^m$ | Land allocated to crop for market | ha |
| vNewcred | Credit added each period | fr.rw |
| vOfflab | Days allocated to off farm activities | man-day |
| *v*Repay | Repayment | fr.rw |
| $\sigma$ | Standard deviation of income | |

The software used for optimization of the quadratic programming farm household model is General Algebraic Modelling System, version 22.6 (GAMS) with the solver CONOPT.

3.2.2.2. Sources of data used

In 2004 and 2005 data were collected in Umutara province by the National Institute of Statistics of Rwanda, in the framework of a national agricultural farm survey held twice annually (details of the survey are provided in Bidogeza et al., 2009). This farm survey database can be obtained from the authors upon request. In addition, a small survey was conducted in October, November and December 2007 through interviews in order to collect information supplementary to the national farm survey. For the latter survey, farm households were asked questions about family expenditure and income, crops and rotations, production costs and output prices, labour use and costs, market availability. Supplementary information related to coefficients of the current farming were estimated from literature (MCDF, 1984; Birasa et al., 1990; Minagri, 1991; Ghent university, 2002; CPR, 2002; Minagri, 2002; Zaongo et al., 2002; Van Ranst, 2003; CIRAD, 2004 and Minagri, 2006). These coefficients are estimated under low input systems. Low inputs are defined as no significant use of purchased inputs such as artificial fertilizers, improved seeds, pesticides or equipment. Input and output prices in the region were derived from the database on the market prices list provided by the Minagri (2007a). Data to generate many of the coefficients for soil characteristics of the region were obtained from the natural resource database hosted by the "Carte Pedologique" Unit at the Ministry of Agriculture (Birasa et al., 1990).

#### 3.2.2.3. Activities

Farm household activities consist mainly of crop production, off-farm activities and hiring in labour or working as farm labour on other farms. Livestock is not a major activity for the farm type considered. Major food crops in Umutara include beans, groundnut, maize, sorghum, cassava, sweet potatoes, and banana. Crop activities in the model are production for sale and production for home consumption, since farm households consume a large part of their own products and sell what remains. Thus, we have assumed in the farm household model that any production above subsistence requirements will be sold.

All crop activities are defined at the level of annual cropping systems except banana and cassava, which are perennial crops. Subsequently, each of the perennial crops is assumed to have equal land area in the two growing seasons.

Table 3.4. presents a summary of input-output information for the different crop activities for season A and for Oxisols. Input-output information for the other season and the other soil type is provided in Appendix A.

Off-farm activities are important for the household systems in Rwanda. Off-farm activities represent an alternative source of income which must be taken into account when maximizing the farm income. Available off-farm activities concern informal sector work and include activities such as running small businesses, hiring out labour or working as vendor in the market etc. The family labour that can be devoted to off-farm activities depends on the available labour of the head of the household since he is the one who is mostly involved in these activities. However, off-farm opportunities are scarce in these rural areas. In our farm household model, we have assumed that a head of household can devote at most 50% of the available time for labour to off-farm activities. The daily wage received by the head of household for participating in off-farm activities is 400 fr.rw. This is the average daily wage for agricultural and informal non agricultural labour in eastern region (Strode et al., 2007).

Hired labour can be used in addition to farm household labour when cash is available. Hence, hired labour and farm household labour may be regarded as perfect substitutes. The wage of hired labour amounts to 400 fr.rw per man-day (Strode et al., 2007).

Borrowing can be seen as an option to supplement insufficient cash in order to finance seeds, hired labour, school fees, etc. Financial institutions could be important sources of credit facilities. However, in practice farmers find it quite difficult to acquire credit from these institutions due to the lack of collateral. Instead, credit can be obtained from informal sources like “credit club”, the primary source of credit in Umutara. Loans plus interest must be repaid at the end of the cropping season. Interest is paid at the rate of 10% per month (Bidogeza et al., 2009) depending on the “credit club” to which a farm household has subscribed. Although that credit can be available, it is constrained by a credit limit .

3.2.2.4. Constraints

Land available for the representatative farm household is based on the average farm size in the eastern region, which is 0.7 hectare (Loveridge et al., 2007). Crops may be grown on two soil types Oxisols and Inceptisols.

Labour requirements for crop activities (Table 3.4.) vary depending on crop development stage. Most of the field operations on crops (land preparation, planting/sowing, crop maintenance, hand weeding and harvesting) have to be performed during a particular period of the season. Thus, each season is divided into three periods of two months. Small-scale farm households typically use family labour. Composition of the household determines labour capacity. The labour capacity of an adult farm household member is 100%, while children (10-18 years) and adults over 65years of age are assumed to have 50% working availability. The available farm family labour may be subject to fluctuations over the year.

Table 3.4. Input-output information on crops for Oxisols

| Season | | A | A | A | A | A | A&B | A&B |
|---|---|---|---|---|---|---|---|---|
| Crop activities | Unit | Beans | Groundnuts | Maize | Sorghum | Sweet potatoes | Cassava | Banana |
| Inputs-output | | | | | | | | |
| Yield[1] | kg $ha^{-1}$ | 670 | 500 | 990 | 1,050 | 6,300 | 6,000 | 15,000 |
| Price[2] | fr.rw $kg^{-1}$ | 141 | 419 | 100 | 106 | 90 | 177 | 83 (98)[a] |
| Revenues | fr.rw $ha^{-1}$ | 94,470 | 209,500 | 99,000 | 111,300 | 567,000 | 1,062,000 | 1,357,500* |
| Cost of seed/establishment cost | fr.rw $ha^{-1}$ | 8,500 | 23,000 | 2,000 | 800 | 23,000 | 50,000 | 93,200* |
| Gross margin | fr.rw $ha^{-1}$ | 85,970 | 186,000 | 97,000 | 110,500 | 544,000 | 1,012,000 | 1,264,300 |
| Labour[3] | man-days $ha^{-1}$ | 104 | 98 | 116 | 108 | 94 | 129 | 264 |
| Total energy[4] | $10^3$kcal $ha^{-1}$ | 2,231 | 2,835 | 3,237 | 3,664 | 5,720 | 6,378 | 5,190[b] |
| Total Protein[4] | g $ha^{-1}$ | 158,120 | 129,000 | 75,240 | 112,350 | 86,310 | 48,000 | 56,250[b] |
| Soil loss[5] | t $ha^{-1}$ | 11.8 | 19.9 | 21.8 | 24.9 | 14.3 | 16.2[b] | 2.5[b] |
| Soil Organic carbon[6] | t $ha^{-1}$ | 3020 | 1887 | 3020 | 1887 | 3775 | 1887[b] | 3020[b] |

[1] Minagri (1991) and Minagari and INSR (2006); [2] Minagri (2007a); [3] MCDF (1984); CIRAD (2004 ) and White et al. (2005) ; [4] WHO (1985); FAO/WHO (2000) and own calculations; [5] Roose (1994), Wischmeier (1995), Roose and Ndayizigiye (1997) , CPR (2002), Lufafa et al. (2003), Fleskens (2007), USDA (2009), and own calculations; [6] Sys et al. (1993) and own calculations.;

; [a] price per Kg of banana, respectively in season A and B.

[b] These values are concerning season A

*The costs and revenues of Banana (multiyear crop) are based on annuities

In fact, for school-going adolescents, labour contributions vary, depending on whether they live at home during school year. Additionally, children also contribute to the farm labour force during their vacations in April, July, November and December. We assume that available labour that can be allocated to activities is equivalent to 5 days per week per adult. However, 1 day per week per adult is substracted since farm households allocate labour to other necessary activities such social and household activities (e.g. firewood and water collection). The total labour requirements for crop production should be met by farm household labour and hired labour.

Rotation restrictions are set for individual crops for agronomic reasons. Crop rotations can be very important for pest and disease control, for maintaining soil fertility and reducing soil erosion. Seasonal crop rotation practices are widely adopted by farmers throughout the country. Crop rotations are incorporated in the model as strict equality constraints and imply that areas of the crops in the rotation are equal. The most frequently adopted rotations for the region are cereals-leguminous (i.e.maize and sorghum with beans and groundnut) and tubers-leguminous (i.e. sweet potatoes with beans and groundnut).

Cash is required to finance expenses of crop production during each cropping season and is a major constraint for small-scale farm households. These expenses include family expenditures, purchase of seeds and hiring labour. Cash is also needed for family expenditures. Cash is available from farm household's own savings made in the previous harvesting season. Moreover, cash may come from off-farm activities and credit. Credit limits set a limit to the amount of credit to be lent to a farmer. The limit varies from 5,000 Fr. Rw to 50,000 Fr. Rw depending on the wealth of the farmer. In the model, we assumed a credit limit of 10,000 fr.rw ( Bidogeza et al., 2009).

Food consumption constraints in the model reflect the need of the household to first secure the household food requirements since the primary objective of small-scale farmers in Rwanda is to provide their families with adequate food . Food purchases have not been considered in model since the food consumption is mainly from the farm's food production. Small-scale farmers can hardly buy food. Consumption constraints are specified to guarantee minimum energy (in kilocalories) and proteins (in grams) per season. The minimum food requirements are obtained from the World Health Organization (WHO) recommendation level of energy and proteins per person (Table 3.5.).

Table 3.5. Energy and proteins recommended by World Health Organization (1985)

| | Energy/day (kcal) | | Proteins/day (gr) | |
|---|---|---|---|---|
| Age | Male | Female | Male | Female |
| 0-11months | 679.8 | 628.3 | 11.9 | 11 |
| 1 to 3 years | 1123 | 1057.3 | 12.8 | 12.2 |
| 4 to 6 | 1454.4 | 1408.5 | 16.7 | 16.9 |
| 7 to 9 | 1758 | 1570 | 22.7 | 22.8 |
| 10 to 12 | 1984.4 | 1805.1 | 28.6 | 30 |
| 13 to 14 | 2177.3 | 1942.6 | 37.8 | 38 |
| 15 to 16 | 2435.7 | 2055.1 | 46.8 | 44.1 |
| 17 to 18 | 2657.2 | 2113.0 | 51.9 | 42.2 |
| 19 to 29 | 3324.8 | 2315.3 | 44.3 | 39.6 |
| 30 to 60 | 3285.6 | 2344.8 | 44.3 | 39.6 |
| 60+ | 2287 | 1886.7 | 44.3 | 39.6 |

Soil organic carbon (SOC) is one of the key factors that affect agricultural production, nutrient availability and soil stability (Tang et al., 2006), particularly in highly weathered Rwanda soils where organic matter is the major source of nutrients. SOC is a dynamic property of soil, not a static one (Cooperband, 2002). The crop requirements for SOC are derived from Sys et al. (1993). The right hand side of the SOC constraint specifies its tolerance value below which yields begin to decrease (Barbier, 1998). Arshad and Martin (2002) suggested that for SOC a decrease of 15% over the average or the baseline value seems reasonable to use as critical value.The baseline SOC values considered are the organic carbon content of the two soil types for a soil depth of 1m (Ghent University, 2002).

Soil loss above certain limits will lead to the degeneration of soil reserve and soil fertility resulting in the destruction of the usable agricultural land. The farm household model takes soil loss into consideration as a constraint. Soil loss values are required for each crop activity. These values are incorporated into a soil loss constraint for each of two land types, respectively Inceptisols and Oxisols. The Wischmeier's model (Universal Soil Loss Equation) is used to calculate the soil loss coefficients (Wischmeier, 1995). The model predicts gross soil loss per unit of land as:

$$A = R*K*L*S*C*P \qquad (15)$$

where A is the estimated soil loss in tons per hectare. R is the rainfall erosivity calculated based on the total kinetic energy of the rainfall and the maximum rainfall intensity over a continuous 30 minute period. It represents the potential erosive risks for a particular region. R values have been derived from the equation (16) and are obtained from measurements in a region of Uganda which has close similarities with Umutara (Lufafa et al, 2003).

$$R = 47.5+0.38*Pr \qquad (16)$$

In formula (16) Pr is the seasonal precipitation (mm). K is soil erodibility and represents soil resistance. K is a function of texture, organic matter, permeability and soil structure. K values for Inceptisols and Oxisols are respectively 0.20 and 0.25 (Roose and Ndayizigiye, 1997; Henao and Baanante, 2006; Fleskens, 2007). L*S represent hillslope length and steepness, and reflects the effect of topography on soil loss rates at a particular site. Values used for

Inceptisols with slope of 4% and Oxisols with slope of 9% are respectively 0.42 and 1.3 (Roose, 1994). C is the land use and land cover factor and expresses effects of surface cover and roughness, soil biomass, soil-disturbing activities on rates of soil loss at particular sites. Values used are obtained from Lewis (1988; cited by Fleskens, 2007). Banana has the lowest C-value of 0.04, while sorghum has the highest C-value of 0.45. P is management practice and expresses the effects of supporting conservation practices, such as contouring, buffer strips, terracing, etc. on soil loss at a particular site. When no erosion control practice is used P equals 1. Planting crops with dispersed trees could be attributed a P value of 0.6, use of grass strips lowers this to 0.4 and grass strips with hedgerows P to 0.1. Thick mulching also has a P of 0.1 (Fleskens, 2007 and Roose, 1994).

The right hand side of the soil loss constraint specifies the soil loss tolerance. The concept of soil loss tolerance is defined as the maximum acceptable soil loss from an area which will allow a high productivity to be maintained for a long period of time. In the model, soil tolerance values used for Oxisols and Inceptisols were derived from Pretorius and Cook (2002), 12 t $ha^{-1}$ $yr^{-1}$ and 16 t $ha^{-1}$ $yr^{-1}$, respectively. Pretorius and Cook (2002) have assigned soil tolerance values to soils depending on their root penetration depth. The Oxisols have generally steeper slopes and lower soil depth, while Inceptisols are on gentle solpes and deeper soils.

#### 3.2.2.5. Inclusion of risk in the farm household model

It is important to account for risk in any agricultural productive activity (Hardaker et al., 2004; Anderson and Dillon, 1992). Risk is defined as a measure of the effect of uncertainty on the decision-maker (Upton, 1996). Farm households in Rwanda are facing an unstable income from season to season due to unpredictable rainfall and fluctuations of market prices. Most small farmers typically behave in risk-averse ways, they are willing to forgo some expected income for a reduction in risk (Acs et al., 2009). Ignoring risk-averse behaviour in farm household models may lead to results that are unacceptable to the farmer, or that have little relation to the decisions he actually makes.

From equation (1) risk is explicitly incorporated in the farm household model. The risk is calculated following a quadratic programming approach (Hazell and Norton, 1986). This method computes the standard deviation from the variance-covariance matrix and the level of the stochastic activities. Since seasonal fluctuations in farm prices and rainfall have a large effect on farmers' income, risk has been calculated for two types of production activities: home consumption and market. To compute risk for home consumption we use gross margin with constant prices, while gross margin with variable prices is used to compute market risk. Data from six years are used to determine the variance and covariance matrix. This is refered to in Table 3.6. for the season A. The variance and covariance matrix table for season B is shown in appendix B.

Given the difficulty to objectively assign a risk aversion parameter for typical farm, we have assumed that small-scale farm households are somewhat risk averse (Ø = 1.0). This value is derived from Anderson and Dillon (1992) as they grouped relative risk aversion as follow :

Ø = 0, risk neutral;

Ø = 0.5, hardly risk averse at all;

Ø = 1.0, somewhat risk averse (normal);

Ø = 2.0, rather risk averse;

Ø = 3.0, very risk averse;

Ø = 4.0, extremely risk averse.

Risk aversion coefficient of 1 is close to the values reported by Dillon and Scandizzo (1978), and Moscardi and de Janvry (1977) who obtained average of values, respectively 0.9 and 1.12

in developing countries. In their study on risk attitudes of substistence farmers in northeast of Brazil, Dillon and Scandizzo (1978) found a weighted average value of risk aversion of 0.9. The results of Moscardi and De Janvry (1977) showed risk aversion coefficient centered around 1.12 in a study conducted on risk attitudes of Mexican farmers. Senkondo (2000) conducted a study in Tanzania on risk attitude and risk perception in agroforestry decisions. Four farmers'situations were examined with respect to risk attitude measures. The risk aversion coefficient of 1 is within the range of values reported by Senkondo (2000), i.e.-0.98 and 2.64 with average value of 0.774 for the situation when the farmer has inadequate food stocks, which is a situation close to the typical farm household.

Table 3.6. Variance/Covariance Matrix of GM with variable prices (VP) and constants prices (CP) for season A

| | Sorghum | | Maize | | Beans | | Peanuts | | Banana | | Sweet Potatoes | | Cassava | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | VP | CP | VP | CP | VP | CP | VP | CP | VP | CP | VP | CP | VP | CP |
| Sorghum | $9.6.10^{8}$ | $5.10^{8}$ | $4.5.10^{7}$ | $2.2.10^{8}$ | $9.8.10^{8}$ | $3.4.10^{8}$ | $2.6.10^{8}$ | $1.01.10^{9}$ | $5.1.10^{9}$ | $1.2.10^{9}$ | $2.9.10^{9}$ | $1.06.10^{9}$ | $2.5.10^{9}$ | $1.9.10^{8}$ |
| Maize | $4.5.10^{7}$ | $2.2.10^{8}$ | $4.7.10^{8}$ | $3.9.10^{8}$ | $4.1.10^{7}$ | $-1.6.10^{7}$ | $5.6.10^{8}$ | $1.1.10^{9}$ | $6.8.10^{8}$ | $2.5.10^{8}$ | $9.5.10^{8}$ | $1.4.10^{9}$ | $2.1.10^{9}$ | $6.3.10^{8}$ |
| Beans | $9.8.10^{8}$ | $3.4.10^{8}$ | $4.1.10^{7}$ | $-1.6.10^{7}$ | $1.4.10^{9}$ | $5.6.10^{8}$ | $8.7.10^{7}$ | $2.5.10^{8}$ | $7.4.10^{9}$ | $1.3.10^{9}$ | $3.8.10^{9}$ | $-5.9.10^{6}$ | $1.5.10^{9}$ | $-2.3.10^{8}$ |
| Peanuts | $2.6.10^{8}$ | $1.01.10^{9}$ | $5.6.10^{8}$ | 1.1.109 | $8.7.10^{7}$ | $2.5.10^{8}$ | $4.5.10^{9}$ | $6.4.10^{9}$ | $-4.1.10^{9}$ | $1.8.10^{9}$ | $1.2.10^{9}$ | $5.9.10^{9}$ | $1.6.10^{8}$ | $1.7.10^{9}$ |
| Banana | $5.1.10^{9}$ | $1.2.10^{9}$ | $6.8.10^{8}$ | $2.5.10^{8}$ | $7.4.10^{9}$ | $1.3.10^{9}$ | $-4.1.10^{8}$ | $1.8.10^{9}$ | $4.10^{10}$ | $5.4.10^{9}$ | 2.7.1010 | $1.6.10^{9}$ | $2.3.10^{10}$ | $2.3.10^{8}$ |
| Sweet Potatoes | $2.9.10^{9}$ | $1.06.10^{9}$ | $9.5.10^{8}$ | $1.4.10^{9}$ | $8.4.10^{9}$ | $-5.9.10^{7}$ | $1.2.10^{9}$ | $5.9.10^{9}$ | $2.7.10^{10}$ | $1.6.10^{9}$ | $1.4.10^{10}$ | $8.9.10^{9}$ | $2.5.10^{10}$ | $2.92.10^{9}$ |
| Cassava | $2.5.10^{9}$ | $1.9.10^{8}$ | $2.1.10^{8}$ | $6.3.10^{8}$ | $1.5.10^{9}$ | $-2.3.10^{8}$ | $1.6.10^{8}$ | $1.7.10^{9}$ | $2.3.10^{10}$ | $2.3.10^{8}$ | $2.5.10^{10}$ | $2.9.10^{9}$ | $4.9.10^{10}$ | $2.95.10^{9}$ |

### 3.2.3. Set up of the calculations

Calculations are made for a typical farm household on Oxisoils and Inceptisoils for the two growing seasons of a year. Table 3.7. shows some specific farm characteristics for the representatative farm household considered in the model. The farm household is composed of one adult male, one adult female, two kids under 10 years old and four children are of age 10-18. This family size follows from the average national rate of birth with six child per woman (Kinzer, 2007). The household is supposed to benefit of the labour from the children while they have vacation. Consequently, the available labour within the household fluctuates within the year as it can be seen from the Table 3.7. Average yearly expenditures of the typical farm household are estimated on the basis of national value representing the consumption poverty line per adult equivalent per year. That value is estimated at 64,000 Rwandese francs per adult equivalent per year (Ansoms and McKay, 2010). The farm household is assumed to have two adults (the head of household and his wife). The children are added to this adult equivalent. For the cash availability, we assume that the farm houshold has a cash of 5,000 Fw.Fr at the beginning of the year (Bidogeza et al., 2009).

Subsequently, the results from the typical farm household model are compared with actually observed values.

Lastly, additional calculations are made with the model to examine the effects of the land area and family size on food security , income and soil loss results. Therefore, the farm household model is optimized with nine different combinations of land area and family size. Three households with a family size of five, eight, and ten persons are combined each, with a land area of 0.5 ha, 0.7 haa and 1 ha, respectively. The household size of five, eight and ten reflect respectively: the Government's policy on family planning which encourages families to have at most 4 children per woman (Solo, 2008); the current average family size (about 8) and a rather high household size, also often encountered in Rwanda. The land areas embody, respectively the possible future, the actual, and the minimum recommended land size.

Table 3.7. Characteristics of the typical farm household used as input in the model.

| | Unit | Farm household |
|---|---|---|
| Total farm size | ha | 0.7 |
| Inceptisols (slope of 4%) | ha | 0.28 |
| Oxisols (slope of 9%) | Ha | 0.42 |
| Family size | person | 8 |
| Available Labour | man-day | |
| Season A | | |
| Period 1 | | 104 |
| Period 2 | | 64 |
| Period 3 | | 144 |
| Season B | | |
| Period 1 | | 64 |
| Period 2 | | 104 |
| Period 3 | | 64 |
| Wage off-farm income | fr.rw/day | 400 |
| Available cash at the start of the year | fr.rw | 5,000 |
| Credit limit per season | fr.rw | 10,000 |
| Rate of interest per month | % | 10 |
| Family expenditure | fr.rw. | 128,000 |
| Energy requirement (Kcal/Household) | | |
| Season A | $10^3$kcal | 3,067 |
| Season B | $10^3$kcal | 3,067 |
| Proteins requirement (Grams/Household) | | |
| Season A | $10^3$ gr | 49 |
| Season B | $10^3$ gr | 49 |

Note: Average exchange rate in 2007: US$1 = 550 Fr.Rw.

## 3. 3. Results and Discussion

Calculations have been made first to determine the optimal farm plan for the typical farm.

### 3.3.1. Technical results

The optimal cropping plan for the typical farm is presented in Table 3.8. A large proportion of land is allocated to banana, beans, sweet potatoes and sorghum which reflects the food habits in Umutara province. Banana and sweet potato have higher calories per hectare while beans have the highest level of proteins per hectare. Banana covers a much larger proportion (47 %) of the land in the optimal farm plan than other crops because of its high calories per hectare. In addition, banana protects well the soil since it causes less soil loss. Sweet potato also has high yield of calories per hectare but, because of the high soil loss rate compared to banana, a smaller land area is allocated to sweet potato than banana. Beans are produced to a relatively large extent ( 20%) because of its highest level of proteins. A small proportion of the available land is allocated to sorghum and groundnut to supply additional calories and proteins and secure the nutritional requirements of the farm household.

From the model results, both nutritional requirements and soil loss are binding constraints. However, soil loss is restricting only on marginal land (Oxisols). Banana and beans cause less erosion compared to other crops. This explains why they are grown mostly on marginal land (70%).

Cassava is not considered in the optimal farm production although it has the highest yield of calories per hectare. The model considers that an optimal plan including cassava is too risky since it has a higher variability of production and prices compared to other crops.

Table 3.8. Optimal cropping plan for season A and B

| Area (ha) | | | | |
|---|---|---|---|---|
| | Season A | | Season B | |
| Land type | Inceptisols | Oxisols | Inceptisols | Oxisols |
| ***Crops for home consumption*** | | | | |
| Banana | 0.067 | 0.209 | 0.067 | 0.209 |
| Beans | 0.035 | 0.161 | 0.056 | 0 |
| Cassava | 0 | 0 | 0 | 0 |
| Groundnut | 0.015 | 0 | 0.006 | 0 |
| Maize | 0 | 0 | 0 | 0 |
| Sorghum | 0.134 | 0 | 0.004 | 0 |
| Sweet potatoes | 0.019 | 0.032 | 0.125 | 0.082 |
| ***Crops for sale*** | | | | |
| Banana | 0.010 | 0.018 | 0.010 | 0.018 |
| Sweet potatoes | 0.0006 | 0 | 0 | 0 |
| ***Unused land*** | 0 | 0 | 0 | 0.112 |
| **Total** | 0.28 | 0.42 | 0.28 | 0.42 |

Technical results for fixed resources, specifically land, on-farm labour and off-farm labour are shown in Table 3.9. The area under Inceptisols is fully used in both seasons, whereas the model leaves 0.112 haa of the area under Oxisols unexploited in season B. This is because of constraining soil loss and SOC. A total of 172 man-days and 106 of man-days remain available, for in seasons A and B, respectively. In both seasons, labour allocated to the off-farm activity is at its maximum level.

In our farm household model we have differentiated the crop production for home consumption from crop production for sale. The model results reveal that 88% of the land is allocated to crop production for home consumption, while 8% remains unused and 4% of land is used for crop production for sale. A large proportion of land for home consumption is needed to secure the World Health Organisation's (WHO) nutritional requirements, i.e. to maintain the food security status. The model results identify soil loss and risk as the major explanations why some land remains idle while a small portion of land is allocated to crop production for sale. At relatively low extent, SOC has some influence on the optimal farm production.

From the model results, crops which contribute mostly to secure calories for the representatative farm household throughout the year are banana and sweet potatoes providing respectively 48% and 26% of total energy, respectively. Beans is the major supplier of proteins with 48% of total proteins required.

### 3.3.2. Economic results

The farm income can come from off-farm activities and crop production for sale. Although there is sale of crops, revenues from crop production for sale are small since the model has allocated major portion of land to crop production for home consumption. Therefore, the major contributor of farm income is from off-farm activities with 55%, while sale of crops production contributes 45%. Net farm income equals to 18,680 fr.rw, yearly. Net farm income is the cash income after substrating the cash expenditures. Banana is almost the only cash crop, because of its high gross margin per hectare. The model has shown that risk and soil loss are playing a role to maintain this subsistence trait. The restricting food requirements explain why the typical farm in our model is willing to forego some land or prefers to grow subsistence crops in order to avoid risk.

The farm household model reports the shadow prices for the fixed resources and constraints that are fully used. A shadow price indicates the maximum amount by which the model's objective function could be increased if an additional unit of the resource were to become available (Hazell and Norton, 1986). For example, in case of land constraint expressed in ha, a shadow price of 1.5 indicates that the objective function would increase by 1.5 if the availabilty of land would increase by one 1 ha. Table 3.9. presents shadow prices of some of the fixed resources and constraints. Off-farm activities are extremely important to the typical farm. One man day labour allocated to off-farm activities would increase farm income with 400 fr.rw. Scarcity of employment opportunities refrain farm households from hiring out labour. In the case of land: the maximum rent a farmer should be willing to pay for one additional hectare of land type Inceptisols would be 63,845 fr.rw and 42,515 fr.rw, respectively in season A and B. Land with Oxisols is only fully used in season A with a shadow price of 16,354 fr.rw.

The farm household model calculates the shadow prices for levels of soil loss for the two types of soil. In the case of soil loss, shadow prices represent the amount by which the objective function would change if the constraint on soil loss were increased by one unit. They represent the maximum allowable cost of erosion reductions (Carcamo et al, 1994). Thus, allowing 1 t $ha^{-1}$ more soil loss can increase farm income with 1,785 fr.rw for Oxisols. The shadow price of soil loss for Inceptisols is zero. Likewise for SOC the shadow price for the Inceptisols is zero, while for Oxisols, it is restricting. This implies that soil loss on Inceptisols and SOC do not entail negative economic consequences. However, in the long run, an acceptable solution from both economic and environmental perspective should be found, i.e. less erosive solution which generates at the same time an acceptable level of profitability.

Table 3.9. Optimal seasonal resource use and constraint and their shadow prices or slack values activities

| | | Season A | | | Season B | | |
|---|---|---|---|---|---|---|---|
| | Unit | Level of activity | Shadow price(fr.rw) | Slack value | Level of activity | Shadow price(fr.rw.) | Slack value |
| Land type | ha | | | | | | |
| Inceptisols (slope: 4%) | | 0.28 | 63,845 | 0 | 0.28 | 42,515 | 0 |
| Oxisols (9%) | | 0.42 | 16,354 | 0 | 0.308 | 0 | 0.112 |
| Soil loss* | t $ha^{-1}$ | | | | | | |
| Inceptisols (slope: 4%) | | 4.48 | 0 | 2.2 | | | |
| Oxisols (9%) | | 5.04 | 1,785 | | | | |
| SOC* | kg $ha^{-1}$ | | | | | | |
| Inceptisols (slope: 4%) | | 1,960 | 0 | 726 | | | |
| Oxisols (9%) | | 2,286 | 163 | 0 | | | |
| On-farm labour Use in: | man-day | | | | | | |
| Period 1 | | 26 | 0 | 58 | 26 | 0 | 18 |
| Period 2 | | 25 | 0 | 19 | 17 | 0 | 66 |
| Period 3 | | 29 | 0 | 95 | 22 | 0 | 22 |
| Off-farm labour use for the head of household | man-day | | | | | | |
| Period 1 | | 20 | 400 | 0 | 20 | 400 | 0 |
| Period 2 | | 20 | 400 | 0 | 20 | 400 | 0 |
| Period 3 | | 20 | 400 | 0 | 20 | 400 | 0 |
| Credit | fr.rw | 10,000 | 0 | 10,000 | 10, 000 | 0 | 10,000 |
| Nutrition requirements | | | | | | | |
| Calories | $10^3$kcal | 3067 | -12.81 | 0 | 3067 | -12.80 | 0 |
| Proteins | $10^3$g | 81 | 0 | 32 | 55 | 0 | 6 |

* Values of soil loss and SOC are for a year.
Note: Average exchange rate in 2007: US$1 = 550 Fr.Rw.

### 3.3.3. Comparison of the household model results with observed household data

The model results are compared with information from literature and farm surveys. With regards to crop allocation the farm model results indicate that banana occupy a large proportion of the land (43%), followed by beans (20%), sweet potatoes (20%) and sorghum (10%). These results are relatively consistent with the information from the farm survey done in the region , which affirms that the most cultivated crops are beans (95 % of the farmers), banana (85%), maize (75%), sweet potatoes (72%), sorghum (70%) and cassava (60% ) (Minagri and INSR, 2006).

Banana and sweet potatoes are known to have less calories and proteins per kg compared to other crops, but are favoured in the model and in the real farming since they have high calories per hectare. Additionally, the two crops tend to produce even when other crops fail completely; they also produce during the nutritionally critical pre harvest period such April-May and November-December (Kangasniemi, 1999). Moreover, banana is causing less soil loss.

Despite its high energy yield per hectare, the model hasn't selected cassava due to its high production and price variance. The cassava production is varying over years because of the recurrent virus of African mosaic which quite often damages the crop (Mukakamanzi, 2004).

The model indicates that a major proportion of crop production is self-consumed to secure nutritional requirements of the typical farm household, a small proportion is sold. The food security status is maintained at the expense of getting cash from the crops. This fact is widely observed in Rwanda where farming is mostly subsistence oriented.

However, the model has attributed a small portion of banana production for sale. This is consistent with the findings from Kangasniemi (1999) and Okech et al. (2001), expressing that in regions where traditional cash crops are missing (coffee and tea), bananas are by far the most remunerative cash crop for Rwandan farmers.

The farm model reveals that the shadow prices of the good land (Inceptisols) are very high compared to the cost of renting one hectare of land per year in southern and eastern regions of Rwanda, which is 22,600 fr.rw. as reported by Takeuchi and Marara ( 2007). However, these shadow prices are more close to the cost of renting one hectare of land per year in the northern region of Rwanda, which is 50,000 fr.rw as reported by Fané et al. (2004). The shadow prices of marginal land are small or zero. Therefore, the model has left out a portion of marginal land where we would expect the farm to fully exploit his farm due to its small size. The cultivation of marginal land causes much more soil loss than cultivation on the good soils, which may explain why the model abandons some of the marginal land because of much soil loss, which may prevent their profitability. Barbier and Bergeron in Honduras (1999) also found that farmers were likely to crop less on erodible fields. Furthermore, we have observed from the farm survey (Minagri and INSR, 2006) that despite of the small size of the farms, 25% of the farmers prefer to put some land on fallow to enrich the soil or because they don't see any profitability to farm the whole farm once not all land is needed for their subsistence.

With regard to labour, the model shows that there is much on-farm labour available since the shadow price is zero, while off-farm activities are used to the maximum. This corresponds with the current situation in Rwanda where off-farm employment is already an important source of income for rural households (Loveridge et al., 2007). However, this option is limited by low availability of off-farm activities. Therefore, availability of off-farm employment would improve the income of farm households.

The results from the bio-economic model of the typical farm provide a valid and acceptable approximation of the reality. Hence, we use the model to test for different policy simulations for the typical farm and also for other farm types.

#### 3.3.4. Effects of household size and land area changes on food security, income and soil loss results.

Table 3.10. indicates the effects of household and land size on food security, income and soil loss results. According to the model, for the majority of farm households, it is possible to meet the WHO nutritional requirements. However, households with 8 members and a farm size of 0.5 ha and household of 10 members with farm size of 0.5 ha and 0.7 ha are not able to secure the WHO energy requirements. Therefore, calorie requirements were lowered (see

Table 3.10.) until a feasible solution was reached. However, from Table 3.10. it can be seen that a household with 5 members and a farm size of either 0.5 ha, 0.7 ha or 1 ha can obtain a high income and that soil loss has relatively little economic impact. This is in accordance with the family planning policy of Rwanda Government which promotes a fertility rate less than 4 children per woman. Indeed, for a household of 5 members even with the lowest farm size (0.5 ha) considered, it is possible to secure the WHO' s recommended level of calories and proteins, and additionnally get a relatively high income. Table 3.10. highlights the fact that with more people having less land food security cannot be achieved and soil loss has a high economic impact at least for the marginal land with Oxisols. This finding seems to contradict the conclusion made by Tiffen et al. (1994). In their study conducted, in Machakos region in Kenya, they asserted that population growth has a positive impact on the economic development. Contrary to the findings of Tiffen et al. (1994): rather than saying "More people, less erosion", our findings indicate that fewer people leads to little economic impact of soil erosion and enough food for each household. However, these differences have to be distinguished by keeping in mind that the farm household model is a yearly based model and under low farming inputs while Tiffen et al (1994) examined interactions of people and environment over a period of sixty years in association with intensive farming systems.

Table 3.10. Effects of household size and land area changes on food security, income and soil loss results.

| Household size (members) | Land area (Ha) | Food Requirements met | | Income in Rwandese francs | Soil loss Shadow prices in Rwandese francs | |
|---|---|---|---|---|---|---|
| | | Energy | Proteins | | Inceptisols | Oxisols |
| | 0.5 | 100 % | 100 % | 33,891 | 0 | 1,964 |
| 5 | 0.7 | 100 % | 100 % | 40,295 | 0 | 603 |
| | 1 | 100 % | 100 % | 41,545 | 0 | 0 |
| | 0.5 | 78 % | 81 % | 17,118 | 0 | 3,703 |
| 8 | 0.7 | 100 % | 100 % | 18,680 | 0 | 1,785 |
| | 1 | 100 % | 100 % | 32,095 | 0 | 1,052 |
| | 0.5 | 62 % | 63 % | 17,118 | 0 | 3,703 |
| 10 | 0.7 | 87 % | 92 % | 4,728 | 0 | 3,988 |
| | 1 | 100 % | 100 % | 17,855 | 0 | 2,062 |

### 3.3.5. General discussion

In this article, a bio-economic farm model has been presented that can be applied for a typical farm household and be used to simulate the impact of family size, farm size, and soil erosion on farm production and food security. The bio-economic farm household model was developed by using a mathematical modelling approach. Here, some of the important underlying assumptions are discussed.

In this paper, we did not consider the option of purchasing food. Considering the option of purchasing food for the current typical farm with very low inputs and a farming fully focussed on subsistence would not represent the reality of livelihoods of farmers in the east region of Rwanda. However, this option may be appropriate for the livestock farms (they are large farm of more than 3Ha) who are also found in the region, but are less important in terms of total population in the province. Castaño (2001) and Laborte et al. (2009) have considered the option of purchasing food in their respective farm household models in the contexts of semi-subsistence and subsistence farming. Livestock activities, however, have been considered in their models. These activities are missing for the typical farm household considered in our model. It is known that livestock activities may constitute an another source of income, which may then allow farmers to purchase food when necessary.

Subsistence farmers used the food produced from their own farms to feed their families. However, during the period of starvation, subsistence farmers may consider the option of purchasing food. In this article, the year considered in the model is assumed to be a 'normal' where farmers do not have to face starvation due to droughts or inundation. Moreover, although that we didn't program the option of purchasing food in our model, which would give more flexibility to household, we have dealt this in a flexible way in the sense that we relaxed the food constraints at the moment when the model was not able to produce enough food (Table 3.10.).

In this article, we have used the method of standard deviation of the gross margin to compute risk instead of safety-first approach, including Target-MOTAD. The reason of that is because of our model have included the safety-first approach principle in the sense that food requirements are explicitly formulated as constraints.

In this paper, we have assumed that the expected utility is the objective function and this is maximized. Subsistence farming characterizes most of the agricultural production of rural developing countries. Mishev et al. (2002) have stated that subsistence farmers are prone to maximize utility functions. Castaño (2001) and Laborte et al. (2009) have conducted empirical studies wherein the objective function was to maximize utility defined as discretionary income, in Andean hillside farms of Columbia and northern Philippines, respectively. Discretionary income is defined as income available for spending after essential expenses have been made. The farmer is assumed to maximise one objective function, which is the expected utility defined as discretionary income minus the risk premium. However, subsistence farmers may, also pursuit several objectives as Berkhout et al. (2010) have shown that there is heterogeneity in the farmer goals and preferences, in relation to the role of farm enterprise. Therefore, not considering all objectives of the farmer in the modelling approach, may lead to the results that differ from the reality. Consequently the results should be analysed with respect to the particular farming system (Van Calker, 2004).

## 3.4. Conclusions

In this paper a bio-economic model was developed to analyse the impacts of family planning, land consolidation and soil erosion on farm production and food security on a typical farm in Rwanda and on other farm types.

The results of the model show that a higher availability of good land increases farm income, whereas a higher availability of marginal land has slight impact on income. Considering that soil erosion is a restricting factor on marginal land, preserving soils against erosion would release more marginal land and increase food production. Farm household income would also benefit from better off-farm employment opportunities.

Household size and land area changes have a large impact on food security, income and soil loss. Our model results suggest that most farm households can satisfy the WHO minimum nutritional requirements. However, with more people and less land it is difficult to fulfill the WHO's energy and proteins requirements. Households with a large family size and small land area can not ensure their food security. The model results show that a household with 8 members and a farm size of 0.5 ha and a household of 10 members with farm size of 0.5 ha and 0.7 ha are not able to secure the WHO energy requirements. Also, results show that soil loss has in those situations a relatively high economic impact. However, households with the lowest person: land ratio easily secure their food security and soil loss has relatively little economic impact for those households.

The outcome of the model supports the Rwanda policy on family planning which intends to encourage every woman to have a human reproduction rate below 4. However, the land policy to encourage farmers with a total land area below 1Ha either to consolidate their land or to quit farming is not supported by the results. Our results show that a household of 5 members with a farm size of at least 0.5 hectare is able to comply with the minimum food security requirements and to get a relatively high income; additionnally the soil loss has little economic impact. In the context of Rwanda with a rapidly growing population, a minimum area of 0.5 ha instead of 1 ha should be considered (for the time being).

Moreover, policy makers should target adoption of technologies that reduce land degradation and risks to further improve food security.

## Appendix A

Table A1. Input-output information on crops for Oxisols in season B

| Season | | B | B | B | B | B | B&A | A&B |
|---|---|---|---|---|---|---|---|---|
| Crop activities | Unit | Beans | Groundnuts | Maize | Sorghum | Sweet potatoes | Cassava | Banana |
| Inputs-output | | | | | | | | |
| Yield | kg $ha^{-1}$ | 690 | 450 | 940 | 1,050 | 6,300 | 6,000 | 15,000 |
| Price | fr.rw $kg^{-1}$ | 167 | 538 | 127 | 118 | 93 | 177 | 83 (98)[a] |
| Revenues | fr.rw $ha^{-1}$ | 115,230 | 242,100 | 119,380 | 123,900 | 585,900 | 1,062,000 | 93,200* |
| Cost of seed/establishment cost | fr.rw $ha^{-1}$ | 10,000 | 30,000 | 2500 | 900 | 30,000 | 50,000 | 1,357,500* |
| Gross margin | fr.rw $ha^{-1}$ | 105,230 | 212,100 | 116,880 | 123,000 | 555,900 | 1,012,000 | 1,264,300 |
| Labour | man-day $ha^{-1}$ | 104 | 98 | 116 | 108 | 94 | 129 | 264 |
| Total energy | $10^3$kcal $ha^{-1}$ | 2,297 | 2,551 | 3,073 | 3,664 | 5,720 | 6,378 | 5,190[b] |
| Total Protein | g $ha^{-1}$ | 162,840 | 116,100 | 71,440 | 112,350 | 86,310 | 48,000 | 56,250[b] |
| Soil loss | t $ha^{-1}$ | 14.4 | 30.4 | 26.6 | 30.4 | 17.5 | 19.7[b] | 3[b] |
| Soil Organic carbon | t $ha^{-1}$ | 3020 | 1887 | 3020 | 1887 | 3775 | 1887[b] | 3020[b] |

[a] Price per Kg of banana, respectively in season A and B.

[b]These values are concerning season B.

*The costs and revenues of Banana (multiyear crop) are based on annuities

Table A2. Input-output information on crops for Inceptisols in season A

| Season | | A | A | A | A | A | A&B | A&B |
|---|---|---|---|---|---|---|---|---|
| Crop activities | Unit | Beans | Groundnuts | Maize | Sorghum | Sweet potatoes | Cassava | Banana |
| Inputs-output | | | | | | | | |
| Yield | kg $ha^{-1}$ | 1,000 | 760 | 1,490 | 1,580 | 7,300 | 7,000 | 17,000 |
| Price | fr.rw $kg^{-1}$ | 141 | 419 | 100 | 106 | 90 | 177 | 83 (98)[a] |
| Revenues | fr.rw $ha^{-1}$ | 141,000 | 318,440 | 149,000 | 167,480 | 657,000 | 1,239,000 | 1,538,000 |
| Cost of seed/ establishment cost | fr.rw $ha^{-1}$ | 8,500 | 18,000 | 2,000 | 800 | 30,000 | 50,000 | 93,200 |
| Gross margin | fr.rw $ha^{-1}$ | 132,500 | 300,440 | 147,000 | 166,680 | 627,000 | 1,189,000 | 1,445,300 |
| Labour | man-day $ha^{-1}$ | 95 | 91 | 110 | 106 | 85 | 91 | 264 |
| Total energy | $10^3$kcal $ha^{-1}$ | 3,330 | 4,309 | 4,872 | 5,514 | 6,628 | 7,440 | 5,882[b] |
| Total Protein | g $ha^{-1}$ | 236,000 | 196,080 | 113,240 | 169,060 | 100,010 | 56,000 | 63,750[b] |
| Soil loss | t $ha^{-1}$ | 3.1 | 1450 | 5.6 | 6.4 | 3.7 | 4.2[b] | 0.7[b] |
| Soil Organic carbon | t $ha^{-1}$ | 2320 | 1450 | 2320 | 1450 | 2900 | 1450[b] | 2320[b] |

[a] Price per Kg of banana, respectively in season A and B.

[b] These values are concerning season A

Table A3. Input-output information on crops for Inceptisols in season B

| Season | | B | B | B | B | B | B&A | B&A |
|---|---|---|---|---|---|---|---|---|
| Crop activities | Unit | Beans | Groundnuts | Maize | Sorghum | Sweet potatoes | Cassava | Banana |
| Inputs-output | | | | | | | | |
| Yield | kg $ha^{-1}$ | 1,050 | 700 | 1,410 | 1,580 | 7,300 | 7,000 | 17,000 |
| Price | fr.rw $kg^{-1}$ | 167 | 538 | 127 | 118 | 93 | 177 | 83 (98)[a] |
| Revenues | fr.rw $ha^{-1}$ | 175,350 | 376,600 | 179,070 | 186,440 | 678,900 | 1,239,000 | 1,538,000 |
| Cost of seed/ establishment cost | fr.rw $ha^{-1}$ | 10,000 | 30,000 | 2500 | 900 | 30,000 | 50,000 | 93,200 |
| Gross margin | fr.rw $ha^{-1}$ | 165,350 | 346,600 | 176,570 | 185,540 | 648,900 | 1,189,000 | 1,445,300 |
| Labour | man-day $ha^{-1}$ | 95 | 91 | 110 | 106 | 85 | 91 | 264 |
| Total energy | $10^3$kcal $ha^{-1}$ | 3,496 | 3,969 | 4,610 | 5,514 | 6,628 | 7,440 | 5,882 |
| Total Protein | g $ha^{-1}$ | 247,800 | 180,600 | 107,160 | 169,060 | 100,010 | 56,000 | 63,750[b] |
| Soil loss | t $ha^{-1}$ | 3.7 | 7.8 | 6.8 | 7.8 | 4.5 | 5.11[b] | 0.8[b] |
| Soil Organic carbon | t $ha^{-1}$ | 2320 | 1450 | 2320 | 1450 | 2900 | 1450[b] | 2320[b] |

[a] Price per Kg of banana, respectively in season A and B.
[b] These values are concerning season B

# Appendix B

Table B1. Variance/Covariance Matrix of GM with variable prices (VP) and constants prices (CP) for season B

| | **Sorghum** | | **Maize** | | **Beans** | | **Peanuts** | | **Banana** | | **Sweet Potatoes** | | **Cassava** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *VP* | *CP* | *VP* | *CP* | *VP* | *CP* | *VP* | *CP* | *VP* | *CP* | *VP* | *CP* | *VP* | *CP* |
| Sorghum | $1.7.10^{9}$ | $2.2.10^{8}$ | $9.6.10^{8}$ | -3.2.107 | $1.6.10^{9}$ | -3.9.106 | $2.1.10^{9}$ | $6.6.10^{8}$ | $1.1.10^{10}$ | $3.2.10^{8}$ | $4.5.10^{9}$ | $-2.10^{8}$ | $1.7.10^{10}$ | $5.3.10^{8}$ |
| Maize | $9.6.10^{8}$ | $-3.2.10^{7}$ | $2.5.10^{9}$ | $6.6.10^{8}$ | $4.3.10^{8}$ | $-1.8.10^{8}$ | $1.5.10^{9}$ | $-3.4.10^{8}$ | $4.5.10^{9}$ | $-3.4.10^{8}$ | $2.2.10^{9}$ | $-5.7.10^{8}$ | $1.1.10^{10}$ | 7.3.107 |
| Beans | $1.6.10^{9}$ | $-3.9.10^{6}$ | $4.3.10^{8}$ | $-1.8.10^{8}$ | $3.10^{9}$ | $4.7.10^{8}$ | $2.3.10^{9}$ | $1.8.10^{7}$ | $1.5.10^{10}$ | 2.6.108 | $6.8.10^{9}$ | $-1.10^{8}$ | $2.5.10^{10}$ | $2.2.10^{9}$ |
| Peanuts | $2.1.10^{9}$ | $6.6.10^{8}$ | $1.5.10^{9}$ | $-3.4.10^{8}$ | $2.3.10^{9}$ | $1.8.10^{7}$ | $4.7.10^{9}$ | $3.1.10^{9}$ | $1.4.10^{10}$ | $1.2.10^{9}$ | $7.4.10^{9}$ | $-6.10^{7}$ | $2.6.10^{10}$ | $1.9.10^{9}$ |
| Banana | $1.1.10^{10}$ | $3.2.10^{8}$ | $4.5.10^{9}$ | $-3.4.10^{8}$ | $1.5.10^{10}$ | $2.6.10^{8}$ | $1.4.10^{10}$ | $1.2.10^{9}$ | $1.4.10^{11}$ | $1.4.10^{9}$ | $5.1.10^{10}$ | $-4.9.10^{8}$ | $1.4.10^{11}$ | $1.6.10^{9}$ |
| Sweet P. | $4.5.10^{9}$ | $-2.10^{8}$ | $2.2.10^{9}$ | $-5.7.10^{8}$ | $6.8.10^{9}$ | $-1.10^{8}$ | $7.4.10^{9}$ | $-6.10^{7}$ | $5.1.10^{10}$ | $-4.9.10^{8}$ | $3.10^{10}$ | $2.9.10^{9}$ | $6.9.10^{10}$ | $-1.3.10^{9}$ |
| Cassava | $1.7.10^{10}$ | $5.3.10^{8}$ | $1.1.10^{10}$ | $7.3.10^{7}$ | $2.5.10^{10}$ | $2.2.10^{9}$ | $2.6.10^{10}$ | $1.9.10^{9}$ | $1.4.10^{11}$ | 1.6.109 | $6.9.10^{10}$ | $-1.3.10^{9}$ | $3.5.10^{11}$ | $2.3.10^{10}$ |

## Chapter 4

# Application of DSSAT crop models to generate altenative production activities under combined use of organic-inorganic nutrients in Rwanda

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## Abstract

*The low agricultural productivity of Rwanda reflects the poor soil fertility status due to a low organic matter and high soil acidity that characterises a large part of the country. Experimental trials have shown that a combined use of organic and inorganic fertilisers can increase crop yield. However, there are no guidelines for combined nutrients of different sources and qualities. Crop growth models can assist in the evaluation of the integration of organic and inorganic fertilisers. The Decision Support System for Agrotechnology Transfer (DSSAT) presents a collection of such crop models. The objective of this paper was to determine alternative production activities through yield prediction of several crops under combined use of organic and inorganic fertilisers on Oxisols and Inceptisols in eastern Rwanda and to determine the best fertility management options. The DSSAT crop models were used to quantify the alternative production activities. The simulation of crop yield showed that predicted crop yield was distinctly higher than the actual yield for the current small-scale farming practices that are common in the region. The predicted yields for beans, groundnuts and cassava were approximately the same for all treatments, while the combined application of Tithonia diversifolia and Diammonium phosphate appeared to predict higher yields for maize and sorghum. Yield prediction for all crops was higher on the Inceptisols than on the Oxisols due to the better chemical and physical conditions of Inceptisols. This is in line with reality*

*Keywords:* Rwanda, DSSAT, crop simulation models, organic fertiliser, inorganic fertiliser, crop yield

## 4.1. Introduction

Rwanda has the highest population density in Africa and population growth is putting an ever increasing pressure on farmland. This pressure on land and water resources leads to the degradation of these resources, which often results in a loss of the production capacity and increasing food insecurity. Rwandan agriculture is currently unable to meet the food needs of the population. In fact, national agricultural production covers only 87% and 70% of the national needs based on the minimum recommended calorie and protein requirements, respectively (Minagri, 2004).

Low agricultural production follows from the low soil fertility status, low organic matter and high soil acidity characterising a large part of Rwanda soils except for the marshy and volcanic land (Gecad, 2004). Traditional techniques of soil fertility regeneration such as fallow are no longer possible because of the exiguity of land. Use of agricultural inputs such as inorganic fertilisers remains insignificant in spite of the context of declining soil fertility (Minagri, 2005) because the prices of inorganic fertiliser are beyond the financial means of small-scale farmers. Furthermore, used alone, mineral fertilisers can lead to problems such as reduced soil fertility, soil acidification, and ground water pollution unless corrective measures are taken (Kwaye et al., 1995; Bekunda et al., 1997). Organic fertilisers such as farmyard manure, crop residues and compost are well accepted and have shown promising results in Rwanda (Dreschsel et al., 1996; Balasubramanian and Sekayange, 1992). However, its production and availability can be limited by labour and land shortage for raising livestock. Other organic systems such as green manuring with leaf biomass from shrubs and trees (e.g. *Calliandra*, *Tithonia*, *Tephrosia*) have shown to be useful for improving soil fertility (Kwesiga and Coe, 1994 ), although use of such practices by farmers is limited due to land shortage to grow those shrubs and trees. The use of organic and inorganic fertilisers relies on different household resources, with inorganic fertilisers requiring financial capital and organic fertilisers mainly requiring labour and land (Place et al., 2003).

Numerous field trials have repeatedly shown the beneficial effects of the combined use of organic and inorganic nutrients on sustainability. This combinatorial approach has proved to increase crop yield while maintaining soil organic matter and reducing soil erosion (Palm et al., 1997). Additionnaly, increased nutrient availability and residual effects are more associated with combined organic and inorganic fertiliser use than with inorganic fertilisers applied alone (Houngnandan, 2000). Given the high cost and uncertain accessibility of inorganic fertilisers in many developing countries, the goal of the combined use of organic and inorganic fertilisers should be to provide as much nutrients as possible through organic materials, making up the shortfall of the limiting nutrients through inorganic fertilisers.

Crop growth simulation models offer possibilities to improve agricultural productivity by generating alternative pruduction activities focused on sustainability (Rabbinge, 1995; Tsuji et al., 1998; Alagarswamy et al., 2000). Such models have been used to generate alternative production activities given the natural environment and under the crop and soil fertility management specified.

In yield trials that were conducted in Rwanda, the combined use of organic and inorganic fertilisers showed a positive effect on crop yield (Dreichsel et al., 1998 ; Rutunga et al., 1998;Ngaboyisonga et al., 2007). Yet there is a lack of rational guidelines on their management (dosage and type of fertiliser). Crop simulation models can assist in evaluating the proportions at which nutrients of different sources and qualities are combined to predict crop yield. The Decision Support System for Agrotechnology Transfer (DSSAT) presents a collection of such crop simulation models that integrate the effects of daily weather data with soil characteristics, crop phenotype and management practices (Jones et al., 2003; Hoogenboom et al., 2004). The programme allows users to generate alternative production practices through the prediction of crop yield and evaluate different options to maximize profit and/or to minimize losses of nutrients. In a recent study Soler et al. (2011) evaluated the performance of DSSAT for simulating soil organic carbon dynamics in Burkina Faso. However, DSSAT has not yet been used for exploring the suitable combined use of organic and inorganic fertilisers under the conditions of tropical Sub-Saharan Africa region.

The objective of this paper was to determine alternative production activities of several crops under combined use of organic and inorganic fertilisers on Oxisols and Inceptisols in eastern Rwanda and to determine the combined use of organic and inorganic fertilisers, which predict high yield for each crop. The DSSAT crop simulation models were used to quantify alternative production activities through the estimation of crop yield.

## 4.2. Materials and methods

### 4.2.1. Description of study area

The Umutara province, with an altitude between 1000 m and 1500 m, belongs entirely to the agro-climatic zone of the Central Bugesera and the Savannahs of the East, which is the driest agro-climatic region of Rwanda. The climate of the province is characterized by four seasons where rainy and dry seasons are alternating annually. The seasons are defined on the basis of their precipitation regime (Sirven et al., 1974). Figure 4.1. shows the average annual pattern of rainfall and potential evapotranspiration of Umutara. The climate thus allows two cropping seasons annually; season A corresponding to the short rainy season from September to January, and season B corresponding to the long rainy season from February to June (Verdoodt and Van Ranst, 2003). Despite the fact that Umutara province is positioned within one agro-climatic zone, there could be high spatial and temporal variability in rainfall that has a serious impact on crop production (Verdoodt and Van Ranst, 2006; Ghent University, 2003). The temperature in the province shows little variation throughout the year, and the average annual temperature can exceed 21°C (Ghent University, 2003).

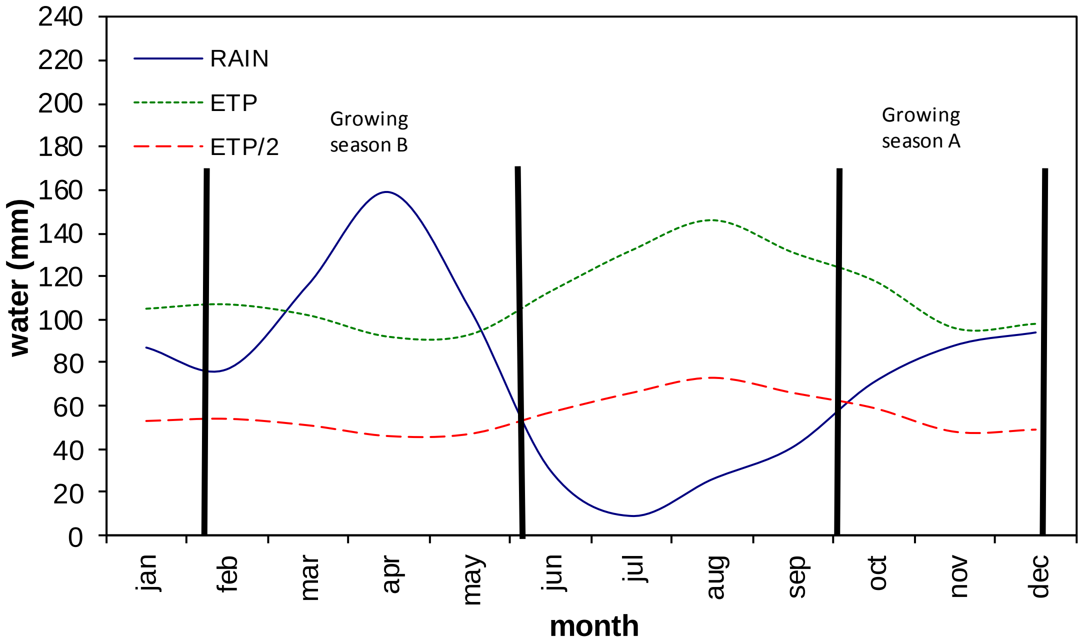


Figure 4.1. Annual variability in rainfall and potential evapotranspiration for Umutara (Bidogeza, 2003).

The pedology of Umutara is quite diverse, notwithstanding that it is a small region. The main soil types of the region are defined as Inceptisols and Oxisols based on the USDA Soil taxonomy (USDA, 1999) and together they occupy 60% of total land area. Oxisols are very highly weathered soils characterised by very low content in high-activity clays. Although most Oxisols have an extremely low soil fertility, they can be productive if lime and fertiliser are applied. Inceptisols in humid tropic are poor in nutrients but still richer than Oxisols and they have a greater cation exchange capacity (FAO, 2001).

The family exploitations cover an area of 63,711 ha. It includes cultivated land, land put in fallow, pastures, wooded areas and land reserved for other uses (e.g. roads and buildings). Cultivated land accounts for 68% of the cultivable land, whereas the fallow, woodland and other uses account for 26%, 2%, 4% respectively (Minagri, 2002). With respect to the importance of the different crops cultivated in the province of Umutara, the highest percentage of the cultivated land is occupied by cereals (33%), followed by tuber crops (29.5%), leguminous crops (21%) and bananas (15%) (Minagri, 2002). Umutara's cattle currently constitute a large share of livestock in Rwanda. Cattle have traditionally represented an important source of income and manure for smallholder farms.

### 4.2.2. Brief description of DSSAT

The Decision Support System for Agrotechnology Transfer (DSSAT) is a microcomputer software designed to facilitate the evaluation and application of the crop models for different purposes (Jones et al., 2003; Hoogenboom et al., 2004). DSSAT was developed by the International Benchmark Sites Network for Agrotechnology Transfert (IBSNAT, 1993) and has been used for more than 25 years by researchers worldwide. DSSAT is a collection of independent programs that operate together; crop simulation models are the core part of the software package. Figure 4.2. summarises the framework of the DSSAT, which is comprised of the following main components: (1) database management system to input, organize, store, retrieve, analyze and display data on crops, soils, and weather, (2) a set of crop models to simulate crop growth, development and yield, (3) application programs to analyze, display and to evaluate the model outcomes with the observed data.

The DSSAT crop models simulate growth, development and yield of crops grown on a uniform area of land under a set of management conditions. As part of the simulation the models consider changes in soil water, carbon and nitrogen that take place under the cropping system over time (Jones et al., 2003). By simulating probable outcomes of crop management strategies, DSSAT offers users information to rapidly appraise new crops, products, and practices for adoption . The recent release of DSSAT version 4.5 incorporates 27 different crops that comprise various crops relevant for Rwanda. The new version facilitates the creation and management of experimental, soil, and weather data file (Hoogenboom et al, , 2010).

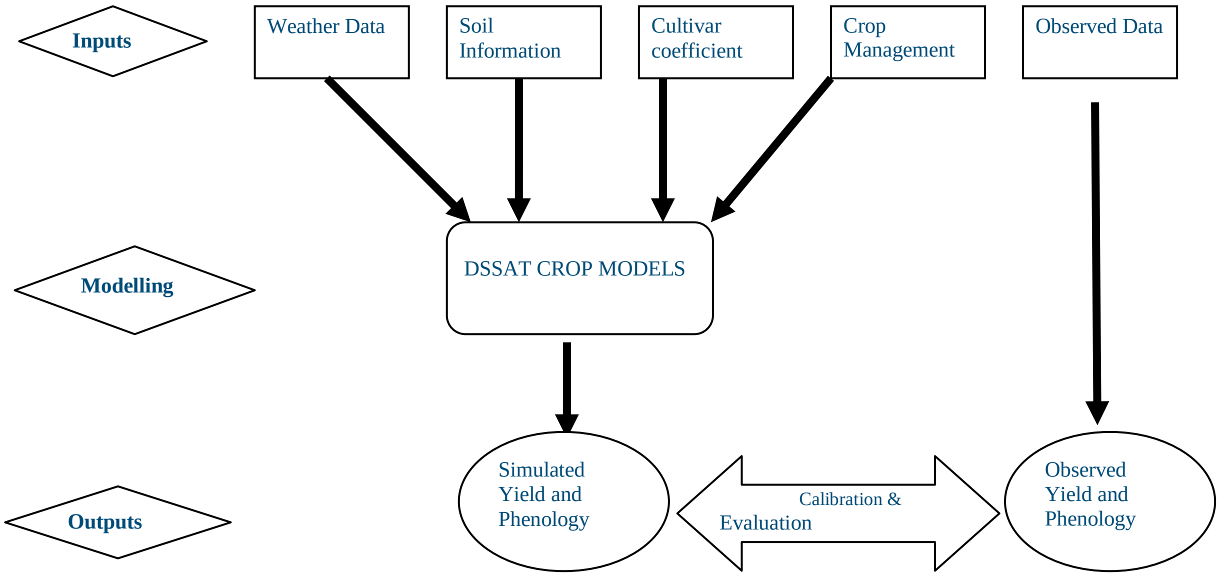


Figure 4.2. Schematic relationships between the three components of DSSAT

### 4.2.3. Data requirements

*Minimum data set (MDS) for model operation*

The Minimum data set (MDS) refers to a minimum set of data required to run DSSAT. The contents of such dataset have been defined by experts from IBSNAT and ICASA (Hunt et al., 2001; Jones et al.,2003), and are shown in Table 4.1. They include data on the site where the model is to be operated, daily weather, local soil surface and profile characteristics, and crop management.

Table 4.1. Minimum data set needed to run the simulation models of DSSAT

| Type | Content |
|---|---|
| Site | Latitude and longitude, elevation; Average annual temperature; slope and aspect; drainage (type, spacing and depth); surface stones (coverage and size) |
| Weather | Daily values of incoming solar radiation; Daily maximum and minimum air temperature; Rainfall. |
| Soil | Classification using local system and (to family level) the USAD-NRCS taxonomy system. Basic profile characteristic by soil layer: saturated drained upper limit, lower limit; bulk density, organic carbon; pH; root growth factor; drainage coefficient. |
| Crop management | Cultivar; Planting date, depth and method; planting density; row spacing and direction;<br>Irrigation and water management, dates, methods and amounts or depths;<br>Fertiliser (inorganic)<br>Residue (organic fertiliser) applications (material, depth of incorporation, amount and nutrients concentrations); tillage<br>Harvest schedule. |

Source: Jones et al. (2003)

*Site and weather data*

The study area is located in the Northeast at 30° 20’ of eastern longitude and 1° 20’ southern latitude with an average elevation of 1,490 m ( Bidogeza, 2003). The soil data were obtained from the database of the Rwandese-Belgian Soil Map project (Ghent university, 2002) and the Rwanda Agriculture Research Institute (Nabahungu, 2010). In Umutara, the weather data were recorded by the two meteorological stations located at Gabiro (1°19’1’’S and 30°19’58’’E )and Nyagatare (1°17’26’’S and 30°19’58’’E) at an elevation of 1,412 m and 1,450 m, respectively. Daily precipitation and maximum and minimum temperature at the Gabiro meteorological station were recorded in 1970. The daily insolation records for Kigali were only available in 1970, and consequently data from the same year had to be used in Gabiro. For the Nyagatare meteorological station, complete daily data on precipitation, maximum and minimum temperatures, and solar radiation were available for 2006. Agricultural years of 1970 and 2006 were considered for simulation since they have complete daily weather data as required for the crop models. Table 4.2. summarises the monthly weather data for 1970 for Gabiro and for 2006 for Nyagatare. 1970 was a relatively wet year while 2006 was more or less average.

Table 4.2. Monthly average value of weather variables used for the crop model simulation.

| Monthly values | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Solar ($MJ/m^2$) | Radiation | Maximum Temperature ($^0C$) | | Minimum Temperature ($^0C$) | | Total Rain (mm) | | Average rainfall over years (1931-1982) (mm) |
| | 1970 | 2006 | 1970 | 2006 | 1970 | 2006 | 1970 | 2006 | |
| Months | | | | | | | | | |
| Jan | 17.3 | 15.6 | 25.9 | 28.5 | 15.0 | 14.3 | 97.80 | 49.00 | 87.0 |
| Feb | 17.1 | 16.1 | 27.1 | 29.0 | 14.8 | 15.4 | 90.90 | 107.0 | 77.0 |
| Mar | 19.0 | 16.1 | 27.6 | 26.9 | 15.2 | 15.7 | 159.7 | 110.4 | 116 |
| Apr | 16.3 | 17.0 | 24.5 | 25.9 | 15.4 | 16.0 | 205.8 | 195.2 | 159 |
| May | 17.2 | 17.3 | 24.9 | 27.0 | 15.3 | 16.0 | 94.10 | 34.00 | 105 |
| Jun | 20.5 | 14.4 | 25.9 | 28.5 | 14.7 | 13.8 | 18.50 | 0.200 | 30.0 |
| Jul | 16.2 | 14.0 | 25.2 | 28.9 | 15.5 | 15.0 | 7.300 | 13.40 | 9.00 |
| Aug | 19.8 | 17.7 | 27.1 | 28.8 | 15.3 | 15.6 | 20.00 | 34.80 | 26.0 |
| Sept | 19.8 | 18.2 | 26.1 | 28.8 | 14.8 | 15.9 | 44.70 | 37.00 | 41.0 |
| Oct | 16.5 | 18.0 | 26.6 | 28.0 | 15.1 | 16.4 | 29.40 | 83.60 | 71.0 |
| Nov | 16.8 | 14.8 | 25.1 | 24.7 | 15.0 | 16.1 | 178.7 | 162.4 | 88.0 |
| Dec | 17.8 | 14.3 | 25.1 | 25.3 | 14.7 | 16.2 | 79.30 | 84.40 | 94.0 |
| | | | | | | | 1126.2* | 911.4* | 903* |

* Total annual rainfall.
Source: Ghent University (2002) and Nabahungu (2010)

*Soil data*

The soil data were obtained from the soil profile database of the Rwandese-Belgian Soil Map project (Ghent university, 2002). Soil profiles for the two dominant soils series Akagera and Rwakibare, representing Oxisols and Inceptisols (USDA soil taxonomy), respectively, were selected for simulation. Oxisols and Inceptisols account for 40% and 20% of all soils in the Umutara region, respectively. The physical and chemical characteristics of these soil series are listed in Table 4.3a. and Table 4.3b., respectively.

Table 4.3a. Chemical and physical properties of soil series Akagera (Inceptisols)

| Soil depth (cm) | Master Horizon | Organic Carbon (%) | Total Nitrogen (%) | Clay (%) | Silt (%) | pH in water | CEC Cmol $Kg^{-1}$ | Bulk Density (g $cm^{-3}$) | Saturated Hydraulic conductivity (cm $h^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|
| 0-16 | A1 | 1.23 | 0.11 | 22.7 | 16.4 | 5.7 | 7.4 | 1.18 | 0.43 |
| 17-30 | A2 | 0.91 | 0.08 | 30.1 | 17.2 | 5.6 | 7.5 | 1.15 | 0.43 |
| 31-43 | BA | 0.68 | 0.07 | 34.1 | 17.9 | 5.7 | 7.8 | 1.33 | 0.43 |
| 44-66 | B1 | 0.52 | 0.05 | 35.7 | 17.8 | 5.5 | 7.2 | 1.41 | 0.12 |
| 67-80 | B2 | 0.48 | 0.05 | 38.9 | 19.6 | 5.4 | 7.1 | 1.25 | 0.23 |
| 81-100 | B3 | 0.39 | 0.04 | 39.4 | 19 | 5.3 | 7.2 | 1.19 | 0.23 |
| 101-130 | C1 | 0.36 | 0.04 | 40.1 | 19.8 | 5.4 | 6 | 1.17 | 0.06 |
| 131-160 | C2 | 0.35 | 0.04 | 39.1 | 20.4 | 5.8 | 7.2 | 1.49 | 0.23 |

Source: Ghent University (2002)

Table 4.3b. Chemical and physical properties of soil series Rwakibare (Oxisols)

| Soil depth (cm) | Master Horizon | Organic Carbon (%) | Total Nitrogen (%) | Clay (%) | Silt (%) | pH in water | CEC Cmol $Kg^{-1}$ | Bulk Density (g $cm^{-3}$) | Saturated Hydraulic conductivity (cm $h^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| 0-25 | A | 0.84 | 0.07 | 21.9 | 8.5 | 6 | 6.2 | 1.51 | 0.43 |
| 26-48 | AB | 0.41 | 0.05 | 33.8 | 6.5 | 6.3 | 5.8 | 1.56 | 0.43 |
| 49-74 | Bo1 | 0.27 | 0.04 | 38 | 6.7 | 5.1 | 5.3 | 1.57 | 0.12 |
| 75-115 | Bo2 | 0.16 | 0.02 | 38.5 | 8.4 | 4.6 | 5.7 | 1.59 | 0.12 |

Source: Ghent University (2002)

*Crop management*

The crops that were simulated included maize, sorghum, dry bean, groundnut and cassava. These crops are among the most important crops in the region because of their role in the diet of local people. Other crops of importance such as banana and sweet potatoes were not considered in the simulation since they are currently not part of DSSAT. For each crop, one cultivar was evaluated. The choice of the cultivar depended on its growth cycle. Cultivars from tropical environments with short growth cycle were favoured.

Crop management referred to the field operations performed during the growing season. Management practices such as sowing date, harvest date, rotation, plant density, row spacing, planting depth were based on the recommendations from the Ministry of Agriculture to intensify farming (Minagri, 2008).

### 4.2.4. Soil fertility management

The soil fertility management simulated was based on a combination of organic materials and inorganic fertiliser. Table 4.4. describes three organic soil fertility practices considered for each crop and alternatively simulated in this study. Crop residues and farmyard manure have been chosen because of their accessibility and affordability for small-scale farmers. *Tithonia diversifolia* is green manure shrub known to supply high nutrient concentrations and is relatively widespread in Rwanda (Mukuralinda, 2007). The nutrient concentrations of organic materials used in the simulation are shown in Table 4.5.

Table 4.4. Organic fertility management practices

| Organic practice | Description |
|---|---|
| Crop residues | The utilization of crop residues may be in the form of leaving residues on the surface or by cutting, chopping, and incorporation of crop residues into the soil. This operation is often done at time of land preparation for the following season. |
| Farmyard manure (FYM) | Mixture of Cattle dung and urine with straw and litter. FYM is popular with the farmers since is considered to be the most effective fertilizer. However, its production is limited as only about one-third of the farms (in general the larger ones) still possess one or more cows |
| *Tithonia diversifolia* | Non-leguminous shrub of the Steraceae family. It is distributed across the tropical zone of Africa and Asia. It is found along the roadsides and on farm boundaries and used as firewood and stakes for climbing bean in Rwanda. It is fast growing species with high nutrients concentrations in the average. It has been intensively tested for use in biomass transfer technologies across east and central Africa. |

Source: Mukuralinda (2007), Frank et al., (2003) and De Jong (1991) .

Table 4.5. Nutrient concentration of organic materials used in the simulation

| Nutrients (%) | Crop residues | Farm yard Manure | Green manure *Tithonia diversifolia* |
|---|---|---|---|
| N | 0,66 | 1,51 | 3.3 |
| P | 0,07 | 0,14 | 0.4 |
| K | 0,3 | 0,91 | 4.1 |

Source: Drechsel and Reck (1998) and Mukuralinda (2007).

The inorganic fertiliser simulated was Diammonium Phosphate *(DAP)*, one of the chemical fertilisers recommended by the Ministry of Agriculture in Rwanda to intensify agriculture. The Ministry has recommanded the use of manure and DAP at the rates of 10 t $ha^{-1}$ and 125 kg $ha^{-1}$, respectively (Minagri, 2008). However, these proportions are beyond the financial means of small-scale farmers and remain exaggerated in view of the current average use of inorganic fertiliser in Rwanda, which is 0.4 kg $ha^{-1}$ (Minecofin, 2003). Therefore, 25% of the recommended inputs have been applied in the simulation model. This may be within reach for the small-scale farmers with limited land and financial means. The treatments in the simulation included: i) T1: crop residues (2,500 kg $ha^{-1}$) and DAP (30 kg $ha^{-1}$); T2: farmyard manure (2,500 kg $ha^{-1}$) and DAP (30 kg $ha^{-1}$); T3: *Tithonia diversifolia* (2,500 Kg $ha^{-1}$) and DAP (30 kg $ha^{-1}$).

## 4.3. Results and discussions

### 4.3.1. Model evaluation

It is very important to establish the credibility of DSSAT crop model outputs with the real data and determine the suitability for the intended purpose. However, the absence of experimental plot data hampered a full evaluation of the performance of the DSSAT crop models. Crop growth simulation models have been applied in Rwanda previously by Verdoodt and Van Ranst (2006), including evaluation with yields reported by small-scale farmer interviews. Hence, the evaluation of DSSAT crop models was based on a comparison of simulated yield without soil fertility practices with average yield observed under the current small-scale farming in the region. Crop management practices such as planting date, planting method, planting density, planting depth, and row spacing were approximated based on small-scale farming practices in the region. Figure 4.3. shows the yield of several crops simulated without soil fertility management practices and yield under small-scale farming in the region. Bean, groundnut and sorghum yield under current small-scale farming were noted to be slighly different from the simulated yield, while maize yields were equal for the two options. Simulated cassava yields were considerably higher than yield under the current small-scale farming. However, cassava cultivars can have potential to yield 3 or 4 times than the native cultivars (Okeke, 1988). Although, the evaluation was limited due to the lack of detailed experimental data, it gave an indication of perfomance of the DSSAT crop models. Thus, comparison of the simulated yields without soil fertility practices and yields under current small-scale farming revealed satisfactory crop models performance with respect to common beans, groundnuts, maize and sorghum, while predicted cassava yields were overestimated.

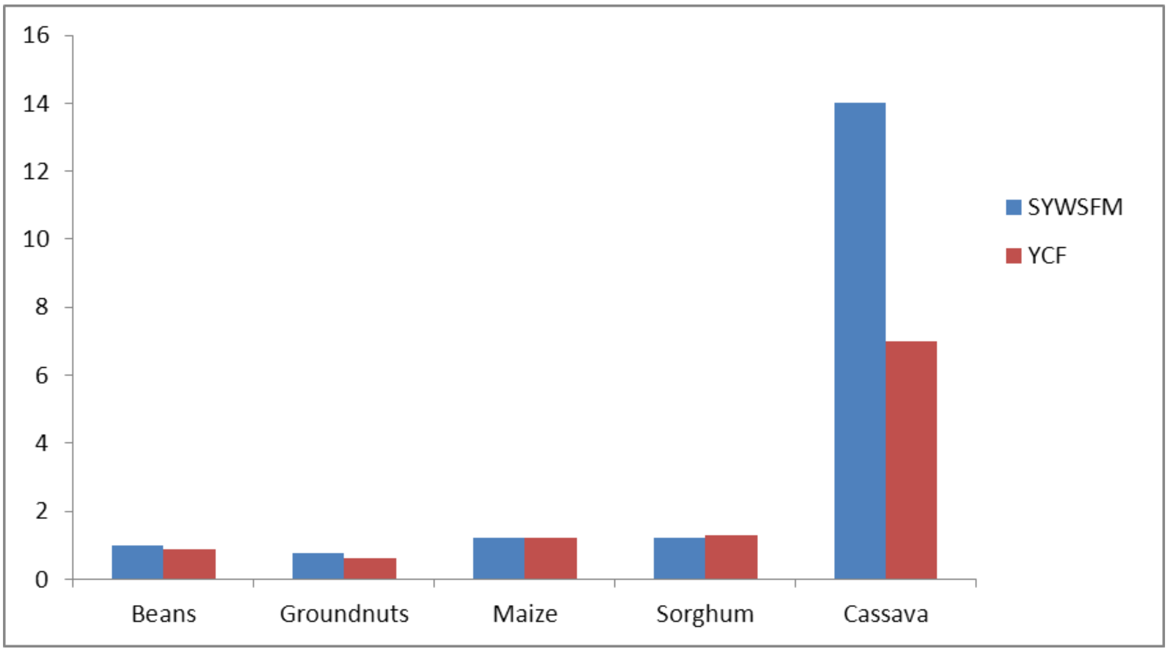


Figure 4.3. Simulated crop yields in t $ha^{-1}$ without soil fertility management (SYWSFM) and crop yields under small-scale farming (YCF)

### 4.3.4. Comparison of soil fertility management

The prediction of bean yield under different combinations of organic materials and inorganic fertiliser was noted to be different from the actual bean yield that has been recorded in the region under current small-scale farming practices, which is 0.8 t $ha^{-1}$ on average (Table 4.6.; Bidogeza et al. 2010). These results show a slight increase in predicted yield in response to the nitrogen level of organic fertiliser. For each year simulated, yields from all the treatments were approximately the same while their nitrogen concentration differ. Since common beans are nitrogen's fixers, the nitrogen requirements are satisfied for the most part by the symbiotic fixation. Consequently, nitrogen from the combined organic materials and chemical fertiliser may not bring much added value for increasing crop yield. The simulated bean yield indicated a higher yield in 2006 than in 1970 for all management scenarios. Although 1970 showed a higher amount of rainfall than 2006, a well distributed rainfall during the development phase of beans was observed in 2006. Good bean yield depends on moderate but well distributed rainfall, i.e. 80 to 120 mm during vegetative growth (Raemaeckers, 2001). The rainfall recorded during the vegetative growth in 2006 was 84.6 mm and 114 mm in season A and B, respectively; while 1970 recorded 30.8 mm and 131.1 mm in season A and B, respectively.

Table 4.6. Beans yield (t $ha^{-1}$) under different combination of organic materials and chemical fertiliser

| Season | Season A | | | | | | Season B | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soil Series | Akagera (Inceptisols) | | | Rwakibare (Oxisols) | | | Akagera (Inceptisols) | | | Rwakibare (Oxisols) | | |
| Year | 1970 | 2006 | mean | 1970 | 2006 | mean | 1970 | 2006 | mean | 1970 | 2006 | mean |
| Treatments | | | | | | | | | | | | |
| T1 | 1.6 | 2.0 | 1.8 | 1.1 | 1.6 | 1.4 | 1.7 | 1.9 | 1.8 | 1.6 | 1.6 | 1.6 |
| T2 | 1.6 | 2.1 | 1.8 | 1.1 | 1.5 | 1.3 | 1.7 | 2.0 | 1.8 | 1.6 | 1.5 | 1.6 |
| T3 | 1.6 | 2.0 | 1.8 | 1.2 | 1.6 | 1.4 | 1.6 | 2.0 | 1.8 | 1.6 | 1.7 | 1.7 |

T1: Crop residues (2,500 kg $ha^{-1}$) + Diammonium phosphate (30kg $ha^{-1}$) ;
T2 : Farmyard manure 2,500kg $ha^{-1}$) + Diammonium phosphate (30kg $ha^{-1}$)
T3: *Tithonia diversifolia* (2,500kg $ha^{-1}$) + Diammonium phosphate (30kg $ha^{-1}$)

Similarly to bean, simulated groundnut yield under different combination of organic materials and inorganic fertiliser was noted to be different from the yield under current small-scale farming in the region, which is 0.6 t $ha^{-1}$ on average (Bidogeza et al., 2010). Table 4.7. summarises the predicted yield of groundnut under a combined use of organic and inorganic fertiliser. All management scenarios showed approximatly the same yield. It has been shown that the rainfall regimes in Rwanda allow for optimal groundnut growth. However, hot and sunny conditions can make a difference in yield since groundnut is drought-resistant crop (Ghent university, 2003). It is known that the rate of transpiration is favoured with hot and sunny conditions among others (Beckett, 1986). Although 1970 and 2006 had sufficient rainfall to meet the requirements of groundnut during the growing season, season A of 2006 produced a higher yield than season A of 1970, whereas season B of 1970 produced a higher yield than season B of 2006. This is possibly due to the higher transpiration of groundnut simulated for season A of 2006 (175.8 mm) than in season A of 1970 (150.3 mm). Similarly, in season B of 1970 150.3 mm of transpiration was simulated compared to 126.2 mm for season B of 2006.

Table 4.7. Groundnuts yields (t ha$^{-1}$) under different combination of organic materials and chemical fertiliser

| Season | Season A | | | | | | Season B | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soil Series | Akagera (Inceptisols) | | | Rwakibare (Oxisols) | | | Akagera (Inceptisols) | | | Rwakibare (Oxisols) | | |
| Year | 1970 | 2006 | mean | 1970 | 2006 | mean | 1970 | 2006 | mean | 1970 | 2006 | mean |
| Treatment | | | | | | | | | | | | |
| T1 | 2.0 | 2.3 | 2.2 | 1.6 | 2.1 | 1.8 | 1.7 | 1.5 | 1.6 | 1.5 | 1.2 | 1.3 |
| T2 | 2.0 | 2.3 | 2.1 | 1.5 | 2.0 | 1.8 | 1.7 | 1.5 | 1.6 | 1.5 | 1.2 | 1.3 |
| T3 | 1.9 | 2.3 | 2.1 | 1.5 | 2.0 | 1.7 | 1.7 | 1.5 | 1.6 | 1.5 | 1.2 | 1.4 |

T1: Crop residues (2,500 kg ha$^{-1}$) + Diammonium phosphate (30kg ha$^{-1}$) ;
T2 : Farmyard manure 2,500kg ha$^{-1}$) + Diammonium phosphate (30kg ha$^{-1}$)
T3: *Tithonia diversifolia* (2,500kg ha$^{-1}$) + Diammonium phosphate (30kg ha$^{-1}$)

The combination of organic materials and chemical fertilisers showed a consistently higher maize yield (Table 4.8.) than the average actual yield under current small-scale farming in the region, which is 1.21 t ha$^{-1}$ (Bidogeza et al., 2010). These results indicated that yield in the model positively responded to an increase in N rate. The smallest increase in maize yield that was predicted was for the combined crop residue and chemical fertiliser application, while the combined green manure and chemical fertiliser showed a significant increase. The smaller increase of the combined crop residue and chemical fertiliser treatment is due to the lower nitrogen content of crop residues. Similar to bean yield, the simulated maize yield was higher for the Akagera soil series than for the Rwakibare soil series due to the better chemical and physical conditions of the Akagera soils.

Table 4.8. Maize yields (t ha$^{-1}$) under different combination of organic materials and chemical fertiliser

| | Season A | | | | | | Season B | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soil Series | Akagera (Inceptisols) | | | Rwakibare (Oxisols) | | | Akagera (Inceptisols) | | | Rwakibare (Oxisols) | | |
| Year | 1970 | 2006 | mean | 1970 | 2006 | mean | 1970 | 2006 | mean | 1970 | 2006 | mean |
| Treatment | | | | | | | | | | | | |
| T1 | 3.8 | 3.7 | 3.8 | 2.3 | 3.6 | 3.0 | 3.8 | 3.5 | 3.6 | 3.2 | 2.4 | 2.8 |
| T2 | 5.2 | 4.8 | 5.0 | 3.3 | 4.8 | 4.3 | 5.1 | 3.7 | 4.4 | 4.1 | 2.9 | 3.5 |
| T3 | 6.1 | 5.4 | 5.7 | 5.6 | 5.4 | 5.5 | 5.8 | 3.2 | 4.5 | 4.6 | 3.0 | 3.8 |

T1: Crop residues (2,500 kg ha$^{-1}$) + Diammonium phosphate (30kg ha$^{-1}$) ;
T2 : Farmyard manure 2,500kg ha$^{-1}$) + Diammonium phosphate (30kg ha$^{-1}$)
T3: *Tithonia diversifolia* (2,500kg ha$^{-1}$) + Diammonium phosphate (30kg ha$^{-1}$)

Simulated sorghum yield was higher under various combinations of organic materials and chemical fertiliser than the yields recorded under current small-scale farming in the region, which is 1.3 t ha$^{-1}$ on average (Table 4.9.; Bidogeza et al., 2010). These results showed that sorghum responded positively to an increase in the N application rate. The smallest simulated increase in sorghum yield was observed for the combined crop residue and chemical fertiliser application, while the highest increase was found for the combined green manure and chemical fertiliser. Simulated sorghum yield for season A for both 1970 and 2006 was quite a bit higher than the yield for season B. This was most likely due to the drought observed during the grain filling phase in season B of 1970 and 2006. Only 1.6 mm was recorded in season B of 2006, while a record of 6.5 mm was observed in season B of 1970 during the grain filling phase. In season A, an average record of 161.8 mm was noted for both 1970 and 2006 during the grain filling period. This is consistent with the results of Benech et al. (1991) who also found a lower rate of dry matter accumulation for sorghum when the grain filling phase was confronted with drought.

Table 4.9. Sorghum yields (t $ha^{-1}$) under different combination of organic materials and chemical fertiliser

| Season | Season A | | | | | | Season B | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soil Series | Akagera (Inceptisols) | | | Rwakibare (Oxisols) | | | Akagera (Inceptisols) | | | Rwakibare (Oxisols) | | |
| Year | | | | | | | | | | | | |
| Treatment | 1970 | 2006 | mean | 1970 | 2006 | mean | 1970 | 2006 | mean | 1970 | 2006 | mean |
| T1 | 3.9 | 4.0 | 3.9 | 3.5 | 3.3 | 3.4 | 3.3 | 3.4 | 3.3 | 2.5 | 2.8 | 2.7 |
| T2 | 5.8 | 5.6 | 5.7 | 5.2 | 5.3 | 5.3 | 3.7 | 3.8 | 3.7 | 3.8 | 3.1 | 3.4 |
| T3 | 6.1 | 6.0 | 6.0 | 5.2 | 5.7 | 5.3 | 3.1 | 3.7 | 3.4 | 5.3 | 3.1 | 4.2 |

T1: Crop residues (2,500 kg $ha^{-1}$) + Diammonium phosphate (30kg $ha^{-1}$) ;
T2 : Farmyard manure 2,500kg $ha^{-1}$) + Diammonium phosphate (30kg $ha^{-1}$)
T3: *Tithonia diversifolia* (2,500kg $ha^{-1}$) + Diammonium phosphate (30kg $ha^{-1}$)

The predicted cassava yields did not respond to an increase of nitrogen content of organic materials (Table 4.10.). Hence, all the management scenarios showed approximately the same yields. The results of the model indicated that predicted cassava yields in 2006 were higher than in 1970, possibly because of the sufficiently well distributed rainfall in the first 6 months of the 2006 growth season. In addition, year 1970 was too wet with unevenly rainfall distributed over the first 6 months of 1970, which is bad for cassava growth .

Table 4.10. Cassava yields (t ha$^{-1}$) under different combination of organic materials and chemical fertiliser

| Season | Season A | | | Season B | | |
|---|---|---|---|---|---|---|
| Soil Series | Akagera (Inceptisols) | | | Rwakibare (Oxisols) | | |
| Year | 1970 | 2006 | mean | 1970 | 2006 | mean |
| Treatment | | | | | | |
| T1 | 16.6 | 20.1 | 18.4 | 15.0 | 17.6 | 16.3 |
| T2 | 16.5 | 18.9 | 17.8 | 15.0 | 17.6 | 16.3 |
| T3 | 16.5 | 19.0 | 17.7 | 14.9 | 17.6 | 16.2 |

T1: Crop residues (2,500 kg ha$^{-1}$) + Diammonium phosphate (30kg ha$^{-1}$) ;
T2 : Farmyard manure 2,500kg ha$^{-1}$) + Diammonium phosphate (30kg ha$^{-1}$)
T3: *Tithonia diversifolia* (2,500kg ha$^{-1}$) + Diammonium phosphate (30kg ha$^{-1}$)

### 4.3.3. Comparison with yield data from practices

The crop model results were also compared with yield data from national and tropical regions, that has reliable information for good commercial rainfed and irrigated yield levels (Sys et al., 1993), rainfed yield attained under common farming practices (Sys et al., 1993) and yields attained under controlled soil fertility management (Minagri, 2008). A comparison of the simulated and reported crop yield is shown in Table 4.11.

The simulated bean yield corresponded well with good commercial yield levels attained under irrigated conditions and yields that are generally reported in Rwanda under controlled fertilizer management. However, the simulated bean yield for the combined organic and inorganic fertilisers were higher than the yield the average farmer rainfed yield. Simulated groundnut yield under combined organic and inorganic fertilisers were approximately the same as good commercial rainfed yield, while good commercial irrigated yield was higher.

Simulated maize yield was to some extent in the range of the reported yield from good commercial practices under rainfed and irrigation conditions. Furthermore, simulated maize yield was also within close range of the yield reported under controlled management conditions of Rwanda. In addition, simulated maize yield agreed with maize yield for combined organic and inorganic material trials that were conducted in southern Rwanda ranging from 2.6 t $ha^{-1}$ to 7.4 t $ha^{-1}$ (Mukuralinda, 2007; Ruganzu, 2009).

Simulated sorghum yield was very similar to the good commercial yield that can be obtained under irrigated conditions and under controlled management as generally reported in Rwanda. However, simulated sorghum yield was overestimated for good commercial rainfed yield and for rainfed yields under common farmers' management practices.

With respect to the yields attained under the different options (Table 4.11.), predicted cassava yields were clearly underestimated by DSSAT compared to reported yields of good commercial rainfed, good commercial irrigated yields and yields under controlled soil fertility management. Nevertheless, the predicted cassava yields were reasonably higher than the reported yields of average farmer rainfed.

Table 4.11. Comparison of the predicted and reported crop yields (t $ha^{-1}$).

| Crop | SYOI[a] | GCRY[b] | GCIY[c] | AFRY[d] | YCC[e] |
|---|---|---|---|---|---|
| Common beans | 1.40 – 1.90 | 1.0 – 1.5 | 1.5 – 2.5 | 0.5 – 1.0 | 1.5 – 2.8 |
| Groundnut | 1.40 – 2.20 | 2.0 – 3.0 | 3.5 – 4.5 | 1.0 – 2.0 | 1.0 – 3.0 |
| Maize | 2.80 – 5.80 | 6 .0- 9.0 | 6.0 – 9.0 | - | 2.0 – 5.0 |
| Sorghum | 2.70 – 6.00 | 2.5 – 3.5 | 3.5 – 5.0 | 1.3 – 2.0 | 2.0 – 4.0 |
| Cassava | 15.0 – 18.0 | 30 – 40 | 35 - 50 | 5.0 - 15 | 20 - 50 |

[a]SYOI, simulated yield under organic and inorganic fertilisers (from DSSAT)
[b]GCRY, good commercial rainfed yield (Sys et al., 1993)
[c]GCIY, good commercial irrigated yield (Sys et al., 1993)
[d]AFRY, average farmer rainfed yield (Sys et al., 1993)
[e]YCC, yield under controlled conditions (Minagri, 2008)

## 4.4. Summary and Conclusions

The objective of this study was to determine alternative production activities through yield prediction of several crops under a combined use of organic and inorganic fertilisers on Oxisols and Inceptisols of eastern Rwanda and to select the best soil fertility management options. This study was conducted with the DSSAT crop simulation models. The yields predicted by the models for a combined use of organic and inorganic fertilisers were distinctively higher than the actual yields obtained for small-scale farming in the region. Predicted crop yields for beans and groundnut did not respond to an increase in the nitrogen fertilizer level, as these crops are leguminous crops and fix nitrogen. Consequently, predicted yield for these crops were appoximately the same for all the management scenarios. However, the combined use of *Tithonia diversifolia* and DAP appeared to predict higher yields for maize and sorghum as these are cereal crops and show a significant response to an increase in nitrogen fertilizer input. All simulated crop yields were higher on Inceptisols than on the Oxisols due to the better chemical and physical conditions of Inceptisols.

The results of the crop models show that the prediction by DSSAT was acceptable and also realistic although detailed experimental data were missing to verify model performance. Nevertheless, comparison of the modelling results with reported yield data revealed a satisfactory crop models performance with respect to common beans, groundnuts, maize, while predicted cassava yields were underestimated and predicted sorghum yields were slightly overestimated.

## Chapter 5

# Potential impact of alternative agricultural technologies to ensure food security and raise income of farm households in Rwanda

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## Abstract

*Rapid population growth and stagnation of agricultural yields in Rwanda have caused a steady decline in food production per capita, a continuous expansion towards the use of marginal land, and a strong degradation of land. The challenge of achieving simultaneously food security, rural welfare, land protection and soil fertility regeneration in the face of its high population is overwhelming to Rwanda. Technical options for a sustainable land use can be available, the major concern is how to induce farmers to adopt these technologies. The objectives of this paper are to assess the potential impacts of the alternative agricultural technologies on income, food production and soil loss for four types of farm households, and to assess policies that could induce adoption of these technologies. Model results show that these alternative agricultural technologies will clearly enhance food production and income for all farm household types except the full- time farm household for which cash at the beginning of the season is too restricted to switch to the new technologies. The outcomes of the model also reveal that alternative technologies will prevent soil loss and improve soil quality since soil loss and SOC do not entail negative economic consequences. Off-farm employment policy will have a high impact on adoption among households with small farms and less off-farm opportunities because it provides cash that is needed to adopt the new technologies. Subsidies on inputs will substantially improve adoption of alternative technologies among literate farm households. Overall, provision of credit and availability of off-farm activities have emerged as policies, that are most likely to enhance adoption of the alternative technologies in all the farm households.*

*Key words*: Rwanda, Current agricultural technologies, Alternative agricultural technologies, Policy incentives, Adoption.

## 5.1. Introduction

The simultaneous occurrence of rapid population growth and stagnation of agricultural yields in large parts of Sub-Saharan Africa (SSA) have caused a steady decline in food production per capita, a continuous expansion of farm marginal land, and a strong degradation of land and reduction of soil fertility (Pinstrup-Andersen, 1994; Lal, 2009). This observation is quite relevant to Rwanda. The land area of Rwanda is 26,388 $km^2$ and it has a population of about 9.3 million. The population density of population is 355 inhabitants/$km^2$, one of the highest in SSA. With the actual population growth of 2.8% per year, this density will double in 25 years. This increasing population pressure means that, without adequate soil use and management, there is land degradation and shortage of food (Rutunga et al., 2007). Land degradation is a serious problem in Rwanda, contributing to the low and declining agricultural productivity. Soil erosion is believed to be the most important cause of land degradation. Clay (1998) states that soil erosion is moderate to severe on 50% of the land area of Rwanda. 14 million tons of soil are lost per year due to soil erosion, which is equivalent to the loss of capacity to feed 40,000 people annually (GoR, 2007b). Two thirds of the land in Rwanda is acidic and exhausted, and continually cultivated because farmers have nowhere else to go and cannot afford to let their land lie fallow. Furthermore, the low income for the majority of farmers makes it impossible for them to apply external inputs that might restore soil fertility and increase production.

The challenge of achieving simultaneously food security, rural welfare, land protection and soil fertility regeneration in the face of its high population is overwhelming to Rwanda. Rwanda's farmers need to pursue a sustainable intensification to maintain food security, protect land and raise cash at the same time. This means using inputs and capital which provide net gains in productivity, but which also protect land and enhance soil fertility over time (Reardon et al., 1996).

Technical options for sustainable land use are available in Rwanda (Drechsel et al., 1996; Drechsel and Reck, 1998; Mukuralinda, 2007; Ruganzu, 2009; Bidogeza et al. 2010b). For example, technological options exist for controlling degradation of land. Soil and water conservation measures (SWC) such as terraces, grass strips, agroforestry trees, mulching, hill-side ditches, hedgerows are just few of the field-level practices experimented and promoted. Other available technologies such as combined use of organic and inorganic fertilisers has shown beneficial effects on soil fertility, soil erosion control, crop yields, and maintenance of soil organic matter (Palm et al., 1997; Place et al., 2003). However, few modelling studies exist at farm -level to analyse the economic impact of these technologies on farmers' wealth in SSA.

Despite their anticipated positive effects on nutrient cycling, soil protection and crop yields, the adoption of sustainable technologies has remained low (Drechsel et al., 1996). Lack of appropriate policy incentives has been noted as a drawback to prevent adoption of new technology. The major concern is how to induce farmers to adopt more sustainable technologies. When emphasis is on adoption of new technology, appropriate incentives are critical to transfer crop management technology (Byerlee, 1994). A range of policy incentives, such as input and output price policies (subsidy and taxation on inputs, support prices and taxation on output), market stabilisation, improvement of infrastructure, access to credit, and availability of off-farm employment can be used to enable farmers to invest in sustainable technologies. However, provision of incentives does not necessarily lead to the adoption of sustainable technology. The adoption of new technology may vary among farm households because of the differences in socio-economic characteristics. Thus, relevant incentives should be targeted to homogenous groups of farm households for the effectiveness of the adoption.

To assess the effects of policy incentives on adoption of sustainable intensification, a combination of agro-ecological and economic approaches is required (Ruben et al. 1998; Kruseman, 2000). This is captured in bio-economic models. In the previous steps of this research, first five farm household types were identified and their socio-economic characteristics with regards to the adoption of new technology were described (Bidogeza et al. 2009). Thereafter, a bio-economic model of one -a typical farm household was developed and tested with the current agricultural technologies (Bidogeza et al, 2010a). Subsequently, alternative agricultural technologies with focus on sustainability were generated using crop simulation models. Alternative agricultural technologies under the combined use of *Tithonia diversifolia* and Diammonium phosphate were selected as new technology and will be tested for adoption in the fourth step since they appeared to generate the highest yields (Bidogeza et al., 2010b). The selected new technology will be tested for four arable household types. One farm type was discarded since it is livestock farm .

The objectives of this paper are: i) to assess the potential impacts of the selected alternative agricultural technologies on farm income, food production and soil loss for four different types of farm households; ii) to assess policies that could induce adoption of alternative agricultural technologies for farm household types, and thus raise income. The analysis was conducted by means of bio-economic modelling. The remainder of this paper is structured as follows. Section 2 gives an overview of policy incentives affecting adoption of new technology. Section 3 presents the materials and methods used. This is followed by section 4, which discusses the simulation results. Thereafter follow the conclusions.

## 5.2. Policy incentives for adoption of sustainable technology: a review of literature

In Sub-Saharan African (SSA), policy incentives to bring about adoption of sustainable agricultural technology by farm households has attracted the attention of policy-makers since the majority of the population derives their livelihoods from agriculture. Sustainable technology seems to offer an opportunity to increase farm income, improve soil quality and prevent soil erosion. Policies play a strong role in providing incentives and disincentives for farmers to invest in sustainable technology (Place and Dewees, 1999). Literature on sustainable technology adoption has stressed the role of different policy incentives such as input and output price policies (subsidy and taxation on inputs, prices support and taxation on output, market stabilisation ), infrastructure policy reflected in transaction costs, access to credit, off-farm employment (Miller and Tolley, 1989; Reardon et al, 1996; Reardon et al., 1999; Kuyvenhoven et al. 1998; Place et al, 2003). The remainder of this section elaborates on these policy incentives for sustainable technology adoption.

*Input and output price policies*

Market interventions such as price support or input subsidies can help to speed up adoption of new technology. When output prices are raised, or prices of inputs are lowered, the profitability of a new technology relative to the old technology may be increased, thus prompting adoption (Miller and Tolley, 1989). However, Woelcke (2006) has established in a study conducted in eastern of Uganda that the improved input-output price relationship alone is not sufficient to induce adoption of agricultural intensification at farm household level. NPK-fertiliser adoption becomes profitable when inputs prices are decreased to 25% of the current value, outputs prices are increased to 50%, and credit is accessible (Woelcke, 2006). For Senegal, researchers showed that farmers' demand for fertilisers was more sensitive to a change in input/output price ratios than to net returns.. Sharp declines in ratios in the mid-1980s led to a drastic reductions of fertiliser use by farmers in the Peanut Basin, despite economic analyses showing that fertiliser use remained profitable (Kelly, 1988).

Researchers have shown that when subsidies of fertiliser were removed, fertiliser use declined substantially in Senegal, Burkina Faso, and Zimbabwe (Kelly et al., 1995; Sawadogo et al., 1994; and Jayne et al., 1994). In a study conducted in Koutiala region in Mali, Kuyvenhoven et al. (1998) noted that an increase of output prices caused an improvement of net revenues and stimulated adoption of sustainable technology, but response multipliers differed among farm types. Large farms adopted more rapidly agricultural intensification practices than small-scale farms.

*Market stabilisation*

High volatility of output prices can negatively affect the adoption of promising new technology. Uncertainty about output prices makes farmers less willing to invest in new technology, which then decreases productivity (Von Braun and Kennedy, 1994). In the Netherlands, results from Acs et al. (2009) showed that the variance of organic revenues has to be reduced by at least 80% of the current variance before the farm would convert to organic production. This is consistent with work conducted by Kim et al. (1992), who found that reduction in the variance of output prices will increase the rate of adoption and speed of diffusion of yield-increasing technologies. Therefore, price stabilization is important and has a positive impact on the adoption of new technology.

*Infrastructure policy*

SSA countries are characterized by significant transaction costs due to poor transportation, communications and other infrastructural constraints. High transaction costs prevent farmers from adopting sustainable technologies (Janvry et al. 1991). Holden and Sheferaw (2002) found that high transaction costs affected the ability and willingness of poor households in Ethiopia to invest in conserving their own land, while Kuyvenhoven et al. (1998) found that reduction of transaction costs are especially relevant to commercially-oriented farms in Mali.

*Credit policy*

Lack of access to cash or credit may constrain farmers from adopting technologies that require initial investments. The credit market in rural areas of SSA remains underdeveloped, with high rates of interest and very limited access for small-scale farm households, which is limiting adoption. From a policy standpoint, economists often view a lack of access to cash or credit as an indication of market failures that decision-makers should help to resolve (Doss, 2006). According to a review by Feder et al. (1985), a number of authors have pointed out that as long as the adoption of the new technology is profitable, even small farmers will find a way to mobilize the relatively small cash requirements for necessary inputs. This would be facilitated with an easy access to credit. However, in her research conducted in eastern Uganda, Woelcke (2006) revealed that the provision of credit alone does not necessarily lead to the adoption of sustainable farming practices. Improved access to credit for small-scale farmers is one essential reform pillar if provided in combination with other measures. In addition, farm households may react distinctively to credit incentives according to the size of their farm. In a study conducted in Indian agriculture, Bhalla (1979) reported that small and large farmers gave different reasons of not using fertilisers in 1970-71 in India: lack of credit was a major constraint for 48% of small farms and for only 6% of large farms. When access to credit was made more difficult, fertiliser use declined substantially in Senegal, Burkina Faso and Zimbabwe (Kelly et al, 1995; Savadogo et al. 1994; and Jayne et al. 1994).

*Off-farm employment policy*

Off-farm income sources may be viewed as an alternative to overcoming certain capital constraints, particularly where credit market is underdeveloped or inaccessible. Thus, off-farm income may enable farmers to invest in new technology. In Burkina Faso, Reardon and Kelly (1989) showed that fertiliser use was positively related to off-farm income in the Sudanian zone . In Rwanda, researchers showed that off-farm income increased soil conservation investments mainly through financing labour hiring and materials. Fernandez-Cornejo et al. (2005) found that adoption of herbicide tolerant soybeans is positively and significantly related to off-farm income for US soybean farmers, after controlling for other factors. However, off-farm incentives may negatively impact on the adoption due to competition for labour between new technology and off-farm activities. In research conducted in Tanzania, Tenge et al. (2004) have shown that involvement in off-farm activities negatively influenced the adoption of SWC measures. About 66% of farm households who were involved in off-farm activities had not conserved any of their fields. Clay et al. (1995) noted that farm households responded differently to off-farm incentives in Rwanda. While off-farm income enabled small-scale farmers to maintain practices such as fallowing, and to purchase food when necessary, it increased the use of purchased inputs among large farms.

## 5.3. Materials and methods

### 5.3.1. Modelling approach

A bioeconomic farm household model was developed for the typical farm in Umutara province (Bidogeza et al., 2010a). The model has the mathematical form of a quadratic programming model:

Maximise $\{Z = c'x - Ø\,\sigma\}$

Subject to $Ax \leq b$

and $x \geq 0$

where: Z = expected utility; c = vector of gross margins, costs or revenues per unit of activity; x = vector of activities; A = matrix of technical coefficients; b = vector of resource availabilities; Ø = risk aversion coefficient (Ø >0); σ = standard deviation of total gross margin.

In this paper, alternative agricultural technologies (Bidogeza et al., 2010b) are evaluated using the model developed with current agricultural technologies (Bidogeza et al.,2010a). Major technologies include crop production for home consumption, crop production for sale, off-farm activities, hiring labour, family expenditures, borrowing credit. Major constraints include land, labour in three different periods per season, rotations, available cash, maximum credit, food consumption requirements, soil loss and soil organic matter. The farmer is assumed to maximise expected utility which is defined as discretionary income minus the risk premium. Discretionary income is defined as income available for spending after essential expenses have been made (Castano, 2001; Laborte et al., 2009). For a more detailed description of the model, see Bidogeza et al. (2010a).

### 5.3.2. Input data for the model

Yields of alternative agricultural technologies were generated from crop simulation models in DSSAT programme (Bidogeza et al., 2010b) and literature. Alternative agricultural technologies under combined use of *Tithonia diversifolia* and Diammonium phosphate were chosen because they appeared to have the best effects on crop yields, soil quality and on soil erosion. *Tithonia diversifolia* is a green manure shrub known to supply high nutrient concentrations, and it is relatively widespread in Rwanda (Mukuralinda, 2007). Diammonium phosphate is one of the chemical fertilisers recommended by the Ministry of Agriculture in Rwanda to intensify agriculture. Yields of other crops of importance such as banana and sweet potatoes were derived from literature since they are not included in the DSSAT programme (Bidogeza et al., 2010b). Yields of banana under green manure were derived from the experiments done by Romero (1998), while yields of sweet potatoes under green manure were obtained from Okpara et al. (2004).

The incorporation of alternative agricultural technologies in the model implies a change in technical coefficients such as yields, labour requirements, soil organic carbon and soil loss. Table 5.1. presents quantitative input-output information on the differences between current and alternative agricultural technologies for season A and for Oxisols, and their sources.

Table 5.1. Input-output information of the current activities (CA) and alternatives activities (AA) for Oxisols[1]

| Season<br>Crop activities<br>Unit | | A<br>Beans | | A<br>Groundnuts | | A<br>Maize | | A<br>Sorghum | | A<br>Sweet potatoes | | A&B<br>Cassava | | A&B<br>Banana | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CA | AA | CA | AA | CA | AA | CA | AA | CA | AA | CA | AA | CA | AA |
| Inputs-output | | | | | | | | | | | | | | | |
| Yield[2] | kg ha-$^{1}$ | 670 | 1,450[2a] | 500 | 1,900[2a] | 990 | 5,520[2a] | 1,050 | 5,340[2a] | 6,300 | 17,000[2b] | 6,000 | 17,000[2a] | 15,000 | 52,000[2c] |
| Price[3] | fr.rw ha$^{-1}$ | 141 | 141 | 419 | 419 | 100 | 100 | 106 | 106 | 90 | 90 | 177 | 177 | 83 (98)[a] | 83 (98)[a] |
| Revenues | fr.rw ha$^{-1}$ | 94,470 | 204,450 | 209,500 | 796,100 | 99,000 | 552,000 | 11,300 | 566,040 | 567,000 | 1,530,000 | 1,062,000 | 3,009,000 | 1,357,500 | 4,706,500 |
| Cost of seed/ establishment cost | fr.rw ha$^{-1}$ | 8,500 | 8,500 | 23,000 | 23,000 | 2,000 | 2,000 | 800 | 800 | 23,000 | 23,000 | 50,000 | 50,000 | 93,200 | 93,200 |
| Cost of chemical fertilizer[4] | fr.rw ha$^{-1}$ | - | 9,600 | - | 9,600 | - | 9,600 | - | 9,600 | - | - | - | 9,600 | - | - |
| Cost of green manure[5] | fr.rw ha$^{-1}$ | - | 75,0005[a] | - | 75,0005[a] | - | 75,000[5a] | - | 75,000[5a] | - | 111,000[5b] | - | 75,000[5a] | - | 120,000[5c] |
| Cost of pesticides[6] | fr.rw ha$^{-1}$ | - | 18,000 | - | 18,000 | - | 33,000 | - | 33,000 | - | 308,000 | - | 418,000 | - | 692,000 |
| Gross margin | fr.rw ha$^{-1}$ | 85,970 | 93,350 | 186,000 | 670,500 | 97,000 | 432,400 | 110,500 | 447,640 | 544,000 | 1,088,000 | 1,012,000 | 2,456,400 | 1,264,300 | 3,801,300 |
| Labour[7] | man-day | 104 | 159 | 98 | 151 | 116 | 170 | 108 | 167 | 94 | 153 | 129 | 166 | 264 | 392 |
| Total energy[8] | $10^3$ kcal ha$^{-1}$ | 2,231 | 4,828 | 2,835 | 10,773 | 3,237 | 18,050 | 3,664 | 18,636 | 5,720 | 15,436 | 6,378 | 18,071 | 5,190 | 17,992[b] |
| Total Protein[8] | g ha$^{-1}$ | 158,120 | 342,200 | 129,000 | 490,200 | 75,240 | 419,520 | 112,350 | 517,380 | 86,310 | 238,000 | 48,000 | 136,000 | 56,250 | 208,000[b] |
| Soil loss[9] | kg ha-$^{1}$ | 11,800 | 1,190 | 19,900 | 2,500 | 21,800 | 2,200 | 24,900 | 2,500 | 14,300 | 10,600 | 16,200 | 1,650[b] | 2,500 | 240[b] |
| Soil Organic carbon[10] | kg ha-$^{1}$ | 3,020 | 3,020 | 1,887 | 1,887 | 3,020 | 3,020 | 1,887 | 1,887 | 3,775 | 3,775 | 1,887 | 1,887[b] | 3,020 | 3,020[b] |

[1] Sources of information on coefficients presented here are concerning AA. These for CA can be consulted in Bidogeza et al, 2010a); [2a] Yields from DSSAT crop models (Bidogeza et al., 2010b); [2b] Okpara and Asiegbu (2004); [2c] Romero (1998); [3]Minagri (2007a); [4] Bidogeza et al. (2010b) and Minagri (2007a); [5a] Bidogeza et al.(2010b) and Minagri (2008); 5b Okpara and Asiegbu (2004) and Minagri (2008); [5c]Romero (1998) and Minagri (2008); [6]Minagri (1993), Minagri (2007b) and Minagri (2008); [7]Jama et al. (1997), Mugabo (2003) and Bidogeza et al.(2010a) ; [8]WHO (1985), FAO/WHO (2000) and own calculations; [9] Roose (1994). Bidogeza et al. (2010a ); [10]Bidogeza et al. (2010a)

[a]price per kg of banana, respectively in seasons A and B; [b]These values are concerning season A.

### 5.3.3. Set up of calculations

Bidogeza et al. (2009) have identified five farm household types among which four were basically arable farm households, while the fifth was a livestock farm. The analysis focused on the four arable farm households named female headed (FEM), tenant (TEN), male literate (MLI) and full-time and illiterate (FIL). Table 5.2. shows some specific farm characteristics for the four arable farm household types. More detailed information on farm characteristics of the farm household types in Rwanda can be found in Bidogeza et al.( 2009). The number of days that heads of households devote to off-farm activities (Table 5.2.) has been calculated based on the ratio of off-farm employment (Bidogeza et al., 2009) and the average number of off-farm days for a typical farm household at national level (Bidogeza et al. 2010a) The analysis was performed on Oxisols and Inceptisols for a period of one year which comprises two growing seasons.

Calculations with current and alternative agricultural technologies are made for the four arable farm household types. For computing risk, the production and price variation for alternative activities are based on the production and price variation of the current activities. Model with current agricultural technologies is considered as base scenario, while model with alternative agricultural technologies is the alternative scenario. The results of current and alternative technologies from the four arable farm household types are compared. Lastly, in the simulation policy, the effect on adopting alternative agricultural technologies of policy incentives such as input and output prices policies (subsidy and taxation on inputs, price support and taxation on outputs) , market stabilisation, infrastructure policy, access to credit and off-farm employment are analysed. The effects of policy instruments on adoption are measured on the basis of percentage change on farm income and land left uncultivated in hectares.

Table 5.2. Characteristics of the different farm household types used as input in the model

| | Unit | Female Headed | Tenant | Male Literate | Fulltime& Illiterate |
|---|---|---|---|---|---|
| Total farm size | ha | 0.53 | 0.3 | 0.75 | 0.92 |
| Inceptisols (slope of 4%) | ha | 0.212 | 0.12 | 0.3 | 0.368 |
| Oxisols (slope of 9%) | ha | 0.318 | 0.18 | 0.45 | 0.552 |
| Family size | person | 5 | 3 | 5 | 7 |
| Available Labour | man-day | | | | |
| Season A | | | | | |
| Period 1 | | 52 | 42 | 74 | 84 |
| Period 2 | | 32 | 32 | 64 | 64 |
| Period 3 | | 72 | 52 | 84 | 124 |
| Season B | | | | | |
| Period 1 | | 32 | 32 | 64 | 64 |
| Period 2 | | 52 | 42 | 74 | 94 |
| Period 3 | | 32 | 32 | 64 | 64 |
| Wage off-farm income | fr.rw $day^{-1}$ | 400 | 400 | 1,000 | 400 |
| Available off-farm labour* | man-day | | | | |
| Season A | | | | | |
| Period 1 | | 6 | 10 | 14 | 4 |
| Period 2 | | 6 | 10 | 14 | 4 |
| Period 3 | | 6 | 10 | 14 | 4 |
| Season B | | | | | |
| Period 1 | | 6 | 10 | 14 | 4 |
| Period 2 | | 6 | 10 | 14 | 4 |
| Period 3 | | 6 | 10 | 14 | 4 |
| Family expenditure | fr.rw $year^{-1}$ | 64,000 | 64,000 | 128,000 | 128,000 |
| Energy requirement (Kcal/Household) | | | | | |
| Season A | $10^3$kcal | 1,748 | 1,087 | 1,880 | 2,670 |
| Season B | $10^3$kcal | 1,748 | 1,087 | 1,880 | 2,670 |
| Proteins requirement (Grams/Household) | | | | | |
| Season A | $10^3$ g | 27 | 17 | 29 | 43 |
| Season B | $10^3$ g | 27 | 17 | 29 | 43 |

Source: Bidogeza et al. (2009)
*Own calculations based on information from Bidogeza et al. (2009) and Bidogeza et al. (2010)

*Input-output prices policies*

With current agricultural technologies, it was assumed that the farmer did not use external inputs except for the seeds. With alternative agricultural technologies, farmers use inputs such as green manure, chemical fertilisers, pesticides, spraying pump, which represent variable costs. In the simulation, prices of inputs and outputs are increased and decreased stepwise and their effects on farm income and on adoption of alternative technologies are analysed for the four arable farm household types.

*Price stabilisation*

In the basic set-up of the model, the variance of prices has been considered. In the policy simulation analysis, we explore how farm income would vary if the market of output would be stable. It means no fluctuation in prices.

*Transaction costs*

The assumption was made that, with current agricultural technologies, transaction costs would be insignificant for subsistence oriented farming. For the alternative agricultural technologies with high production, good or poor infrastructure were considered in the model for the production to be marketed. Thus, 12 fr.rw $ha^{-1}$ of crop production to be marketed was assigned as transaction cost associated with transportation (Jagwe et al., 2010). The effect on farm income and adoption is determined by stepwise decrease and increase of the transaction costs.

*Credit*

In the basis scenario it was assumed that farm households borrow from informal and formal sources to supplement cash to finance their expenses (i.e. agricultural inputs and other expenses). Although that credit can be available, it is constrained by a credit limit. Since alternative agricultural technologies require more inputs, an increase of the credit limit may be supportive when necessary. In the analysis, the effect on farm income and adoption of the stepwise increase of the credit limit is determined.

*Off-farm employment*

Rwanda is intending to increase off-farm employment to 30% by 2012, which will require a creation of 600,000 new non-farm jobs (GoR, 2007b). This big push is expected to reduce the share of the population deriving their livelihoods from subsistence agriculture, thus accelerating agriculture growth. Off-farm employment is simulated in the model. In the basic model , it was assumed that the head of the household is the only one involved in off-farm activities. Due to scarcity of off-farm activities, it was assumed that the head of household can devote at the most 50% of the available time for labour to off-farm activities. In the simulation, we explore the effect on farm income of the stepwise increase and decrease of labour allocated to off-farm activities by the head of household.

## 5.4. Results and discussion

In order to assess the impact of alternative agricultural technologies on food production, soil loss and farm income in eastern province of Rwanda, the four types of farm households with alternative agricultural technologies are analysed and compared to the base run scenario. Technical and economic results of these types of farm households are analysed and compared. Next, the results of policy simulation are discussed.

### 5.4.1. Technical results

The optimal production plan for FEM with current production technologies and alternative production technologies is presented in Table 5.3., while optimal production plans for the rest of the typical farm households can be found in appendices. In FEM, a large proportion of land is allocated to sorghum, beans, banana and sweet potatoes in the base run. Banana and sweet potato have higher calories per hectare while beans have the highest level of proteins per hectare. Additionnally, banana and beans protect well the soil since they cause less soil erosion compared to others. Sorghum is produced on a larger area compared to other crops ( 26%) because of its merit to have both high level of calories and proteins. A relatively small proportion of land is allocated to maize to supply additional proteins and calories to secure nutritional requirements. In the base run, nutritional requirements and soil loss are identified as the major constraints to crop production. Furthermore, in FEM the model results reveal that 72% of the land is allocated to crop production for home consumption, while 25 % remains unused and 3% of land is used for crop production for sale. A large proportion of land for home consumption is needed to maintain the food security status. In the base run, the model results reveal that soil loss is the major explanation why portion of land is left uncultivated.

With alternative production technologies, 83% of the land is allocated to banana, cassava, sorghum and groundnut. The rest of the land (17%) remains unexploited. Banana and cassava were selected as the most profitable crops with higher gross margins, while sorghum and groundnut were cultivated because of their high calories and proteins per hectare, respectively. Likewise as for the base run, some land was left unused with alternative production technologies. Since the soil loss constraint is removed with alternative technologies, the model reveals that cash is constraining at the beginning of the season. Thus, the farmer prefers to leave out a portion of land since he does not have enough cash to buy the required inputs to cultivate the whole land. Unlike to the base run, with alternative technologies FEM devotes 26% of land to crop production for home consumption while more than 56% of land is allocated for crop production for sale. With alternative technologies, nutritional requirements are no longer constraining since there is much crop production. Hence, farmers shift from subsistence food production to market oriented food production with alternative production technologies.

In a similar manner to FEM, the optimal cropping plans for TEN, MLI and FIL follow the same trends of land allocation in the base run. A large proportion of land is allocated to sorghum, maize, beans, banana and sweet potatoes though that small differences for areas under crops can be observed between farms. In the base run, a large proportion of land is devoted to crop production for home consumption in all farm types, while a small portion of land is allocated to crop production for the market and left uncultivated. Soil erosion is the main reason for leaving out some land.

With the introduction of alternative technologies in the model, likewise to FEM, TEN and MLI allocate a large proportion of land to sorghum, groundnut, cassava and banana (Table 5.3. and appendice A1). Furthermore, areas devoted to crop production for the market are substantially larger than land allocated to crop production for home consumption or left uncultivated. A lack of sufficient cash to purchase external inputs required by alternative technologies is the major explanation of land left uncultivated. In FIL with the fulltime farmer and less off-farm activities, lack of sufficient liquidity at the beginning of the season has become much worse to such an extent that the model is too cash-restricted to allow a feasible solution.

Table 5.3. Optimal cropping plan for the base and alternative scenarios for farm household female headed (FEM)

| Area (ha) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Base run | | | | Alternative scenario | | | |
| | Season A | | Season B | | Season A | | Season B | |
| Land type | Inc | Ox | Inc | Ox | Inc | Ox | Inc | Ox |
| ***Crops for home consumption*** | | | | | | | | |
| Banana | 0.002 | 0.047 | 0.002 | 0.047 | 0 | 0 | 0 | 0 |
| Beans | 0.054 | 0.181 | 0 | 0.004 | 0 | 0 | 0 | 0 |
| Cassava | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Groundnut | 0 | 0.1 | 0 | 0.036 | 0 | 0.162 | 0 | 0 |
| Maize | 0.028 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sorghum | 0.123 | 0 | 0.159 | 0 | 0 | 0 | 0 | 0.119 |
| Sweet potatoes | 0 | 0.017 | 0.050 | 0.048 | 0 | 0 | 0 | 0 |
| ***Crops for sale*** | | | | | | | | |
| Banana | 0.001 | 0.003 | 0.001 | 0.003 | 0.056 | 0 | 0.056 | 0 |
| Beans | 0 | 0.021 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cassava | 0 | 0 | 0 | 0 | 0.156 | 0.021 | 0.156 | 0.021 |
| Groundnut | 0.0004 | 0 | 0 | 0 | 0 | 0.134 | 0 | 0 |
| Sweet potatoes | 0.004 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ***Unused land*** | 0 | 0.048 | 0 | 0.215 | 0 | 0 | 0 | 0.177 |
| **Total** | 0.212 | 0.318 | 0.212 | 0.318 | 0.212 | 0.318 | 0.212 | 0.318 |

### 5.4.2. Economic results

The modelling results report the shadow prices for the fixed resources that are fully used. A shadow price indicates the maximum amount by which the model's objective function could be increased if an additional unit of the resource were to become available (Hazell and Norton, 1986). Table 5.4. present shadows prices of some of the fixed resources and constraints for the base run model and the model with alternative technologies, respectively.

In the base run, in FEM, the area under Inceptisols is fully used in the both seasons with an average shadow price of 33, 000 fr.rw, whereas the model leaves 0.263 ha of the area under Oxisols uncultivated. This is because of constraining soil loss since Oxisols are more subject to soil erosion.

With alternative technologies, the area under Inceptisols is fully used in both seasons with an average shadow price of 1 million Rwandese francs, while Oxisols are fully used only in season A with the same shadow price. Areas under Oxisols of 0.177 ha are left uncultivated in season B because of insufficient cash to purchase required external input at the beginning of the season to crop the whole land. Unlike to the base scenario, it is seen in FEM that alternative technologies have prevented soil loss and improved soil quality since the shadow prices of soil loss and SOC are zero, respectively (Table 5.4.). This implies that soil loss and SOC do not entail negative economic consequences. Additionally, alternative agricultural technologies have reduced soil loss to less than one tenth for Inceptisols, while for Oxisols a reduction of soil loss to only one third is noted (Table 5.4.). Furthermore, SOC has been improved by 58 kg $ha^{-1}$ for the Inceptisols, while a raise in SOC of 300 $kgha^{-1}$ is observed for the Oxisols (Table 5.4.). The alternative agricultural technologies have considerably prevented soil loss and improved soil quality in such way that they no longer negatively impact on farm income.

Overall, with alternative technologies land becomes highly valued in the FEM, TEN and MLI farm types, since they provide high gross margins and prevent soil loss especially on the marginal soils (Oxisols).

In the base run, available labour was more than enough throughout the year for all the farm types. With alternative technologies, although they are labour demanding activities, labour was still available but at relatively small extent (Table 5.4.). Keeping in mind that all land is not cultivated because of lack of sufficient cash, this may explain why available labour is not used at its maximum capacity in the alternative technologies scenario. From Table 5.4., it can be seen that off-farm activities are important for farmers for base run and alternative technologies scenarios. However, high shadow prices of off-farm activities observed with alternative activities show that these are very important. Indeed, the shadow prices in the scenario of alternative technologies are 14 to 30 times higher than in the base run scenario Off-farm activities have a high impact for farm households in the alternative technologies scenario since they are an important source of cash to pay for the costs of external inputs.

In the base run scenario, the model results have shown that available credit has not been used in all the farm types since there are less external inputs required by the current production technologies. Thus, available cash at the beginning of the season is sufficient. In the alternative technologies scenario, the available credit is fully used in FEM, TEN and MLI with an average shadow price of 15 Rw. Fr.

Table 5.4. Optimal seasonal resource use and constraints and their shadow prices or slack values for the base and alternative scenarios for the farm household female headed (FEM)

| | | Base run scenario | | | | | | Alternative scenario | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Season A | | | Season B | | | Season A | | | Season B | | |
| | Unit | Level of activity | Shadow price(fr.rw) | Slack value | Level of activity | Shadow price(fr.rw.) | Slack value | Level of activity | Shadow price (fr.rw) | Slack value | Level of activity | Shadow price (fr.rw) | Slack value |
| Land type | ha | | | | | | | | | | | | |
| Inceptisols (slope: 4%) | | 0.212 | 33,378 | 0 | 0.212 | 32,748 | 0 | 0.212 | $1.4.10^{6}$ | 0 | 0.212 | 0 | 0 |
| Oxisols (9%) | | 0.270 | 0 | 0.048 | 0.103 | 0 | 0.215 | 0.318 | $1.3.10^{6}$ | 0 | 0.141 | 0 | 0.177 |
| Soil loss* | kg ha$^{-1}$ | | | | | | | | | | | | |
| Inceptisols (slope: 4%) | | 2,592 | 0 | 798 | | | | 153 | 0 | 3,238 | | | |
| Oxisols (9%) | | 3,810 | 1,368 | 0 | | | | 1,176 | 0 | 2,634 | | | |
| SOC* | kg ha$^{-1}$ | | | | | | | | | | | | |
| Inceptisols (slope: 4%) | | 770 | 0 | 715 | | | | 712 | 0 | 793 | | | |
| Oxisols (9%) | | 1173 | 0 | 557 | | | | 865 | 0 | 895 | | | |
| On-farm labour Use in: | man-day | | | | | | | | | | | | |
| Period 1 | | 24 | 0 | 28 | 17 | 0 | 15 | 47 | 0 | 5 | 14 | 0 | 18 |
| Period 2 | | 24 | 0 | 8 | 18 | 0 | 34 | 22 | 0 | 10 | 15 | 0 | 37 |
| Period 3 | | 27 | 0 | 45 | 23 | 0 | 9 | 25 | 0 | 47 | 26 | 0 | 6 |
| Off-farm labour use for the head of household | man-day | | | | | | | | | | | | |
| Period 1 | | 6 | 400 | 0 | 6 | 400 | 0 | 6 | 7,405 | 0 | 6 | 7,405 | 0 |
| Period 2 | | 6 | 400 | 0 | 6 | 400 | 0 | 6 | 7,405 | 0 | 6 | 7,405 | 0 |
| Period 3 | | 6 | 400 | 0 | 6 | 400 | 0 | 6 | 7,405 | 0 | 6 | 7,405 | 0 |
| Credit | fr.rw | | | | 10,000 | 0 | 10,000 | | | | 10, 000 | 17.4 | 0 |
| Nutrition requirements | | | | | | | | | | | | | |
| Calories | $10^3$kcal | 1,750 | -7.6 | 0 | 1,750 | -9.2 | 0 | 1,750 | -0.073 | 0 | 1,750 | -0.073 | 0 |
| Proteins | $10^3$g | 27 | 0 | 42.6 | 27 | 0 | 12.8 | 27 | 0 | 52 | 27 | 0 | 26 |

* Values of soil loss and SOC are for a year.

Note: Average exchange rate in 2007: US$1 = 550 Fr.Rw.

The economic results follow from technical results (Table 5.5.). In the base run scenario, banana is the major crop which is contributing to the gross margin of FEM at a rate of 40%, while in the alternative scenario banana and cassava are contributing more than 85% of the total gross margin (Table 5.5.). Banana and cassava are the most profitable crops in the two scenarios with a nuance that cassava production does not exist in base scenario since it is causing more erosion, which is not the case in the alternative scenario. Gaidashova et al. (2005) and Mukakamanzi (2004) endorsed the cash crop aspect of the two crops. The former revealed that banana is the most remunerative crop, providing 60 to 80% of the revenues in Rwanda, while the latter noticed that most of the 67% of the farmers marketed 35 to 55% of the cassava production. Despite that costs of production are considerably higher in the alternative scenario compared to the base run, the gross margins remain extremely high for the FEM (Table 5.5.).

Table 5.5. Economic results (in fr.rw) of female headed for the base and alternative scenarios

| | Base run scenario | Alternative scenario |
|---|---|---|
| Returns from sales of crops | | |
| Banana | 6,308 | 261,816 |
| Cassava | - | 526,575 |
| Groundnut | 122 | 106,845 |
| Bean | 1,974 | - |
| Sweet potatoes | 2,610 | - |
| Maize | 4,100 | - |
| Sorghum | - | - |
| Total | 15,114 | 895,236 |
| Cost | | |
| Seeds | 11,102 | 20,995 |
| Pesticides | - | 121,970 |
| Organic fertiliser | - | 35,597 |
| Inorganic fertiliser | - | 7,404 |
| Rent of spray pump | - | 2,824 |
| Transaction costs | - | 73,464 |
| Total | 11,102 | 262,254 |
| Gross margin | 4,012 | 632,982 |
| Value of self-consumed crops | | |
| Banana | 67,141 | - |
| Cassava | - | - |
| Groundnut | - | 129, 471 |
| Bean | 25,176 | - |
| Sweet potatoes | 71,664 | - |
| Maize | | |
| Sorghum | 50,772 | 59,118 |
| Total | 214,753 | 188,589 |

Note: Average exchange rate in 2007: US$1 = 550 Fr.Rw.

TEN has the smallest gross margin compared to others because of its smaller farm (Table 5.6.). MLI has the highest gross margin (Table 5.6.). MLI gets more opportunities to be involved in kind of 'well paid off-farm activities' compared to other farmers, thus they can afford to overcome cash requirements to crop the maximum land, thus increase income. Insufficient cash requirements for inputs has constrained FIL at such extent that the model could not get a feasible solution. FIL with the largest farm, the least off-farm opportunities and the biggest family size could not adopt alternative agricultural technologies because of lack of cash at the beginning of the season. The very or even extreme high gross margins observed for FEM, TEN and MLI under the alternative agricultural technologies have to be seen as the optimal attainable performance, keeping in mind that some constraints could be hardly be captured by the model. Indeed, farmers may struggle to access to inputs at the right time, in the right quantity and quality which would affect negatively crop production.

Table 5.6. Summary of the land use and gross margin results for the different farm households with alternative scenario.

| | FEM | TEN | MLI | FIL |
|---|---|---|---|---|
| Land use (ha) | | | | |
| Banana | 0.112 | 0.32 | 1.09 | - |
| Beans | - | - | - | - |
| Cassava | 0.354 | 0.03 | - | - |
| Groundnut | 0.305 | 0.09 | 0.128 | - |
| Maize | - | - | - | - |
| Sorghum | 0.119 | 0.11 | 0.205 | - |
| Sweet potatoes | - | - | - | - |
| Land left uncultivated | 0.177 | 0.051 | 0.077 | - |
| Gross margin (fr.rw) | 632,982 | 471,669 | 1,512,956 | - |

### 5.4.3. Policy simulations

Following the technical and economic results in sections 3.1 and 3.2, respectively, it was noted that alternative agricultural technologies have clearly enhanced the resource use efficiency in the FEM, TEN and MLI. However, these three Farm Types did not fully adopt the alternative technologies since there is some land left uncultivated because of the cash constraint. Cash at the beginning of the season has become too restricted for FIL at such an extent that it was impossible for the household to afford external inputs. Although alternative agricultural technologies increase food production, Kuyvenhoven et al. (1998) reported additional policy interventions are considered that permit a further improvement of net revenues. In the sensitivity analysis, policy incentives that might affect the farm income and bring about farmers to increase adoption of alternative technologies are examined in the following section. The main results can be seen in Table 5.7.

If off-farm opportunities have to be reduced to 50%, farm income decreases considerably to 53% and 44% in TEN and MLI, respectively. In FEM, an infeasible solution occurs in the model because it was not possible for the model to meet the cash requirements. Cash has become too restricted for the model to allow a feasible solution, while the FIL model remains unfeasible due to cash restriction as well. Off-farm activities constitute a major cash providers to farmers to purchase external inputs, its reduction affects the optimal plan production in such way that more land is left uncultivated. For instance, following the reduction of 50 % of off-farm activities, 0.112 ha and 0.264 ha were left uncultivated in TEN and MLI, respectively. This is because cash became scarce to purchase further external inputs to cultivate the whole land. If the off-farm opportunities have to increase with 50 %, farm income improves slightly to 24%, 18% and 8% in FEM, TEN and MLI, respectively, while the model in FIL remains unfeasible. Available cash from the off-farm activities have enabled TEN and MLI to fully adopt the alternative technologies. Although the increase of off-farm activities allows FEM to acquire cash to meet the expenses of external inputs and thus to improve farm income, an area of 0.154 ha is left uncultivated. The 50% of off-farm increase was not enough to release sufficient cash to purchase required inputs to fully adopt alternative technologies, thus to cultivate the whole land. A sensitivity analysis reveals that for the FIL, an increase of 350% of off-farm activities was needed for the farmer to start adopting alternative technologies.

The results of a more stable market have caused an improvement of farm income with an increase of 3% in TEN and MLI, while in FEM an increase of 5% is observed. Though market stabilization slightly increases farm income, alternative technologies are not totally adopted since some land remains uncultivated.

The results of the sensitivity analysis reveal that when the prices of outputs decrease with 10% of the current price farm income decreases by a range between 16% and 17% in FEM, TEN and MLI, while a rise of 10% of the current price improves farm income with the same range. The rate of adopting alternative technologies is much higher when the price of output is increased by 10% as can be seen in Table 5.7.

Reducing the price of inputs to 10% of the current price improves the farm income by 9%, 8% and 5% in TEN, MLI and FEM, respectively, while an increase of 10% reduces farm income in the same range. Subsidised inputs have highly impacted adoption of alternative technologies in MLI 0.005 ha of land are not exploited with subsidy, while 0.114 ha of land are left uncultivated with no subsidy. Lowering input prices slightly increases the rate of adoption of alternative technologies in FEM and TEN (Table 5.7.). Subsidising inputs allows farmers to purchase more external inputs, thus more land can be cropped, which implies alternative technologies to be adopted. However, subsidised inputs did not stimulate the full-time farmer FIL to adopt alternative technologies. A decrease of 10% of inputs did not make the model feasible for FIL.

The results of the sensitivity analysis reveal that if the transaction costs decrease by 10 % farm income increases by a range between 1% and 2% in FEM, TEN and MLI, while a rise of 10% reduces farm income with the same range. However, the rate of adoption of alternative technologies has not been affected neither by a decrease of transaction costs nor by its increase since the land left unexploited has remained more or less the same (Table 5.7.).

If the provision of credit has to be reduced by 50%, FEM and TEN are highly affected since their farm income drops by 15%, while MLI is less affected with only a drop of 4% of income. Unlikely, when credit increases by 50% farm income rises in the same range. Credit has a higher impact on the rate of adoption in FEM and TEN than in MLI (Table 5.7.).

Table 5.7. Farm households responses to various policy scenarios (percentage change in farm income and areas left uncultivated in hectare)

| Farm household type | Indicators | Off-farm opportunities (-50%) | Off-farm opportunities (+50%) | Price stabilization (variance removed) | Price of outputs (-10%) | Price of outputs (+10%) | Price of inputs* (-10%) | Price of inputs* (+10%) | Transaction cost (-10%) | Transaction cost (+10%) | Credit Supply (-50%) | Credit Supply (+50%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FEM | Farm income | | 24 | 5 | -16 | 16 | 5 | -5 | 1 | -1 | -16 | 16 |
| | Land left uncultivated | Infeasibility occurrence | 0.154 | 0.199 | 0.2 | 0.177 | 0.174 | 0.191 | 0.177 | 0.177 | 0.208 | 0.158 |
| TEN | Farm income | -53 | 18 | 3 | -17 | 17 | 9 | -7 | 2 | -2 | -15 | 15 |
| | Land left uncultivated | 0.112 | 0 | 0.062 | 0.062 | 0.039 | 0.035 | 0.065 | 0.049 | 0.053 | 0.074 | 0.009 |
| MIL | Farm income | -44 | 8 | -3 | -16 | 16 | 8 | -7 | 2 | -2 | -4 | 4 |
| | Land left uncultivated | 0.264 | 0 | 0.077 | 0.077 | 0.047 | 0.005 | 0.114 | 0.075 | 0.077 | 0.102 | 0.02 |
| FIL | Farm income | | | | | | | | | | | |
| | Land left uncultivated | Infeasibility occurrence | | | | | | | | | | |

*Inputs include seeds, pesticides, organic and inorganic fertiliser.

The latter has many opportunities of off-farm income, thus cash is not as restricted as it is for FEM and TEN. The availability of more credit can ease the cash restriction for FEM and TEN, thus allow to buy more inputs and cultivate more land. A sensitivity analysis reveals that in order for FIL to start adopting alternative technologies, provision of credit has to increase by 250%. Credit constitutes an important source of cash for farmers with less off-farm income opportunities.

#### 5.4.4. Policy implications

The results of this study lead to a certain number of relevant policy implications. Alternative agricultural technologies are much more profitable and improve the resource use efficiency. However, adoption of alternative agricultural technologies is hampered by a cash constraints. Therefore, policies should focus on those measures that reduce the cash constraints. Off-farm employment and credit policies have a high impact on adoption among households with small farms and less off-farm opportunities because they provide cash that is needed to adopt the new technologies. Subsidies on inputs substantially improve adoption of the alternative technologies among literate farm households.

## 5.5. Conclusions

The objectives of this paper were to assess the potential impacts of the alternative agricultural technologies on farm income, food production and soil loss for four types of farm households, and to assess policies that could induce adoption of these technologies.

The study concludes that under current socio-economic conditions alternative agricultural technologies are not fully adopted in FEM, TEN and MLI, while FIL cannot pursue a sustainable agricultural intensification. Although alternative technologies have improved farm income in the FEM, TEN and FIL, further policy incentives are needed to improve net revenues in these farm households and induce FIL to start adopting alternative technologies. Model results show that alternative agricultural technologies will clearly enhance the resource use in all types of farm households except the household with the largest farm for which cash at the beginning of the season is too restricted to allow a feasible solution. High food production provided by alternative technologies allow farmers to shift from subsistence food production to market-oriented food production. Areas devoted to crop production for the market are substantially larger than land allocated to crop for home consumption.

The outcomes of the model reveal that alternative technologies have prevented soil loss and improve soil quality since soil loss and SOC do not entail negative economic consequences.

The model highlights the extreme importance of off-farm income to overcome the costs of external inputs required with alternative technologies. This is underlined by the much higher shadow prices observed in the alternative scenario than in the base run.

Off-farm employment simulation reveals that off-farm income is critical for all the types of farm households to adopt alternative technologies. However, the higher adoption's resulting from off-farm employment is in particular positive in farm households with small farms and less off-farm opportunities, respectively. Off-farm activities constitute a major source of cash to purchase external inputs required by alternative technologies. Subsidy on input has a higher impact on adoption of alternative technologies in literate farm household than other types of farms, with much opportunities of off-farm activities. Credit has highly impacted the rate of adoption among farm households characterised mainly by small farms and less off-farm opportunities, respectively.

Provision of credit and availability off-farm activities have emerged as the most serious policies likely to affect the adoption of alternative technologies in all the farm households.

## Appendix A

Table A.1a. Optimal cropping plan for the base run (current activities) and alternative scenario (Alternative activities) for TEN&MLI

| Area (ha) | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TEN | | | | | | | | MLI | | | | | | | |
| | Base run scenario | | | | Alternative scenario | | | | Base run scenario | | | | Alternative scenario | | | |
| | Season A | | Season B | | Season A | | Season B | | Season A | | Season B | | Season A | | Season B | |
| Land type | Inc | Ox | Inc | Ox | Inc | Ox | Inc | Ox | Inc | Ox | Inc | Ox | Inc | Ox | Inc | Ox |
| ***Crops for home consumption*** | | | | | | | | | | | | | | | | |
| Banana | 0.006 | 0.044 | 0.006 | 0.044 | 0 | 0 | 0 | 0 | 0 | 0.005 | 0 | 0.005 | 0 | 0 | 0 | 0 |
| Beans | 0.0360 | 0.105 | 0 | 0 | 0 | 0 | 0 | 0 | 0.117 | 0.131 | 0.055 | 0.065 | 0 | 0 | 0 | 0 |
| Cassava | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Groundnut | 0 | 0 | 0 | 0 | 0 | 0.039 | 0 | 0 | 0 | 0.107 | 0 | 0.039 | 0 | 0.041 | 0 | 0 |
| Maize | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.161 | 0.091 | 0.053 | 0.004 | 0 | 0 | 0 | 0 |
| Sorghum | 0.071 | 0 | 0.078 | 0 | 0 | 0.036 | 0 | 0.074 | 0.016 | 0 | 0.151 | 0 | 0 | 0.077 | 0 | 0.128 |
| Sweet potatoes | 0.003 | 0.010 | 0.035 | 0.028 | 0 | 0 | 0 | 0 | 0 | 0 | 0.040 | 0.027 | 0 | 0 | 0 | 0 |
| ***Crops for sale*** | | | | | | | | | | | | | | | | |
| Banana | 0.001 | 0.003 | 0.001 | 0.003 | 0.120 | 0.040 | 0.120 | 0.040 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.300 | 0.245 | 0.300 | 0.245 |
| Beans | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.026 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cassava | 0 | 0 | 0 | 0 | 0 | 0.015 | 0 | 0.015 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Groundnu | 0.0002 | 0 | 0 | 0 | 0 | 0.051 | 0 | 0 | 0.0008 | 0.0005 | 0 | 0 | 0 | 0.087 | 0 | 0 |
| Sweet potatoes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.005 | 0 | 0.0007 | 0 | 0 | 0 | 0 | 0 |
| ***Unused land*** | 0 | 0.016 | 0 | 0.105 | 0 | 0 | 0 | 0.051 | 0 | 0.196 | 0 | 0.348 | 0 | 0 | 0 | 0.077 |
| **Total** | 0.120 | 0.180 | 0.120 | 0.180 | 0.120 | 0.180 | 0.120 | 0.180 | 0.300 | 0.450 | 0.300 | 0.450 | 0.300 | 0.450 | 0.300 | 0.450 |

Table A.1b. Optimal cropping plan for the base run (current activities) and alternative scenario (Alternative activities) for FIL

| Area (ha) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | FIL | | | | | | | |
| | Base run scenario | | | | Alternative scenario | | | |
| | Season A | | Season B | | Season A | | Season B | |
| Land type | Inc | Ox | Inc | Ox | Inc | Ox | Inc | Ox |
| ***Crops for home consumption*** | | | | | | | | |
| Banana | 0 | 0.027 | 0 | 0.027 | - | - | - | - |
| Beans | 0.074 | 0.270 | 0.039 | 0.089 | - | - | - | - |
| Cassava | 0 | 0 | 0 | 0 | - | | - | - |
| Groundnut | 0 | 0 | 0 | 0 | - | - | - | - |
| Maize | 0.126 | 0.004 | 0.027 | 0 | - | - | - | - |
| Sorghum | 0.163 | 0 | 0.242 | 0.182 | - | - | - | - |
| Sweet potatoes | 0 | 0.027 | 0.062 | 0.057 | - | - | - | - |
| ***Crops for sale*** | | | | | | | | |
| Banana | 0.001 | 0.002 | 0.001 | 0.002 | - | - | - | - |
| Beans | 0 | 0.042 | 0 | 0 | - | - | - | - |
| Cassava | 0 | 0 | 0 | 0 | - | - | - | - |
| Groundnut | 0.0005 | 0.0004 | 0 | 0 | - | - | - | - |
| Sweet potatoes | 0.005 | 0 | 0 | 0 | - | - | - | - |
| ***Unused land*** | 0 | 0.177 | 0 | 0.375 | - | - | - | - |
| **Total** | 0.370 | 0.550 | 0.370 | 0.550 | - | - | - | - |

Table A.2a. Optimal seasonal resource use and constraint and their shadow prices or slack values for the base run for TEN

| Farm household type | | TEN | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Base run scenario | | | | | | Alternative scenario | | | | | |
| | | Season A | | | Season B | | | Season A | | | Season B | | |
| | Unit | Level of activity | Shadow price (fr.rw) | Slack value | Level of activity | Shadow price (fr.rw.) | Slack value | Level of activity | Shadow price (fr.rw) | Slack value | Level of activity | Shadow price (fr.rw) | Slack value |
| Land type | ha | | | | | | | | | | | | |
| Inceptisols (slope: 4%) | | 0.120 | 39.518 | 0 | 0.120 | 37,966 | 0 | 0.120 | $1.7.10^{6}$ | 0 | 0.120 | 69,736 | 0 |
| Oxisols (9%) | | 0.164 | 0 | 0.016 | 0.075 | 0 | 0.105 | 0.180 | $1.3.10^{6}$ | 0 | 0.129 | 0 | 0.044 |
| Soil loss* | $kg\ ha^{-1}$ | | | | | | | | | | | | |
| Inceptisols (slope: 4%) | | 1,366 | 0 | 554 | | | | 15 | 0 | 1905 | | | |
| Oxisols (9%) | | 2,160 | 0 | 1,802 | | | | 612 | 0 | 1,548 | | | |
| SOC* | $kg\ ha^{-1}$ | | | | | | | | | | | | |
| Inceptisols (slope: 4%) | | 450 | 0 | 390 | | | | 556 | 0 | 290 | | | |
| Oxisols (9%) | | 753 | 0 | 226 | | | | 672 | 0 | 313 | | | |
| On-farm labour | man-day | | | | | | | | | | | | |
| Use in: | | | | | | | | | | | | | |
| Period 1 | | 20 | 0 | 22 | 16 | 0 | 16 | 30 | 0 | 12 | 24 | 0 | 8 |
| Period 2 | | 20 | 0 | 12 | 16 | 0 | 20 | 23 | 0 | 9 | 22 | 0 | 20 |
| Period 3 | | 21 | 0 | 31 | 19 | 0 | 13 | 29 | 0 | 23 | 29 | 0 | 3 |
| Off-farm labour use for the head of household | man-day | | | | | | | | | | | | |
| Period 1 | | 10 | 400 | 0 | 10 | 400 | 0 | 10 | 5,704 | 0 | 10 | 5,704 | 0 |
| Period 2 | | 10 | 400 | 0 | 10 | 400 | 0 | 10 | 5,704 | 0 | 10 | 5,704 | 0 |
| Period 3 | | 10 | 400 | 0 | 10 | 400 | 0 | 10 | 5,704 | 0 | 10 | 5,704 | 0 |
| Credit | fr.rw | | | | 10,000 | 0 | 10,000 | | | | 10,000 | 14 | 0 |
| Nutrition requirements | | | | | | | | | | | | | |
| Calories | $10^{3}$kcal | 1,088 | -8.5 | 0 | 1,088 | -10.5 | 0 | 1,088 | -0.072 | 0 | 1088 | -0.047 | 0 |
| Proteins | $10^{3}$g | 17 | 0 | 24 | 17 | 0 | 5 | 17 | 0 | 22 | 17 | 0 | 16 |

* Values of soil loss and SOC are for a year.
Note: Average exchange rate in 2007: US$1 = 550 Fr.Rw

Table A.2b. Optimal seasonal resource use and constraint and their shadow prices or slack values for the base run for MLI

| Farm household type | | MLI | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Base run scenario | | | | | | Alternative scenario | | | | | |
| | | Season A | | | Season B | | | Season A | | | Season B | | |
| | Unit | Level of activity | Shadow price (fr.rw) | Slack value | Level of activity | Shadow price (fr.rw.) | Slack value | Level of activity | Shadow price (fr.rw) | Slack value | Level of activity | Shadow price (fr.rw) | Slack value |
| Land type | ha | | | | | | | | | | | | |
| Inceptisols (slope: 4%) | | 0.300 | 10,531 | 0 | 0.300 | 13,064 | 0 | 0.300 | $1.8.10^{6}$ | 0 | 0.300 | 23,205 | 0 |
| Oxisols (9%) | | 0.254 | 0 | 0.196 | 0.102 | 0 | 0.348 | 0.450 | $1.3.10^{6}$ | 0 | 0.273 | 0 | 0.077 |
| Soil loss* | kg $ha^{-1}$ | | | | | | | | | | | | |
| Inceptisols (slope: 4%) | | 3,317 | 0 | 1,483 | | | | 39 | 0 | 4,761 | | | |
| Oxisols (9%) | | 5,400 | 373 | 0 | | | | 1,029 | 0 | 4,371 | | | |
| SOC* | kg $ha^{-1}$ | | | | | | | | | | | | |
| Inceptisols (slope: 4%) | | 1,271 | 0 | 829 | | | | 1,392 | 0 | 723 | | | |
| Oxisols (9%) | | 1,095 | 0 | 1,353 | | | | 2,107 | 0 | 354 | | | |
| On-farm labour Use in: | man-day | | | | | | | | | | | | |
| Period 1 | | 38 | 0 | 36 | 29 | 0 | 35 | 64 | 0 | 10 | 57 | 0 | 7 |
| Period 2 | | 39 | 0 | 25 | 31 | 0 | 43 | 50 | 0 | 14 | 48 | 0 | 26 |
| Period 3 | | 36 | 0 | 48 | 35 | 0 | 29 | 66 | 0 | 18 | 64 | 400 | 0 |
| Off-farm labour use for the head of household | man-day | | | | | | | | | | | | |
| Period 1 | | 14 | 1,000 | 0 | 14 | 1,000 | 0 | 14 | 13,650 | 0 | 14 | 13,650 | 0 |
| Period 2 | | 14 | 1,000 | 0 | 14 | 1,000 | 0 | 14 | 13,650 | 0 | 14 | 13,650 | 0 |
| Period 3 | | 14 | 1,000 | 0 | 14 | 1,000 | 0 | 14 | 13,650 | 0 | 14 | 13,650 | 0 |
| Credit | fr.rw | | | | 10,000 | 0 | 10,000 | | | | 10,000 | 13 | 0 |
| Nutrition requirements | | | | | | | | | | | | | |
| Calories | $10^3$kcal | 1,879 | -0.4.1 | 0 | 1,879 | -0.4.1 | 0 | 1,879 | - 0.0.072 | 0 | 1,879 | -0.047 | 0 |
| Proteins | $10^3$g | 29 | 0 | 47 | 29 | 0 | 33 | 29 | 0 | 35 | 29 | 0 | 28 |

* Values of soil loss and SOC are for a year.
Note: Average exchange rate in 2007: US$1 = 550 Fr.Rw

Table A.2c. Optimal seasonal resource use and constraint and their shadow prices or slack values for the base run for FIL

| Farm household type | | FIL | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Season A | | | Season B | | | Season A | | | Season B | | |
| | Unit | Level of activity | Shadow price (fr.rw) | Slack value | Level of activity | Shadow price (fr.rw.) | Slack value | Level of activity | Shadow price (fr.rw) | Slack value | Level of activity | Shadow price (fr.rw) | Slack value |
| Land type | ha | | | | | | | | | | | | |
| Inceptisols (slope: 4%) | | 0.370 | 23,523 | 0 | 0.370 | 21,806 | 0 | - | - | - | - | - | - |
| Oxisols (9%) | | 0.373 | 0 | 0.177 | 0.175 | 0 | 0.375 | - | - | - | - | - | - |
| Soil loss* | kg ha$^{-1}$ | | | | | | | | | | | | |
| Inceptisols (slope: 4%) | | 4,491 | 0 | 1,410 | | | | - | - | - | | | |
| Oxisols (9%) | | 6.600 | 71 | 0 | | | | - | - | - | | | |
| SOC* | kg ha$^{-1}$ | | | | | | | - | - | - | | | |
| Inceptisols (slope: 4%) | | 1,403 | 0 | 1,187 | | | | - | - | - | | | |
| Oxisols (9%) | | 1,718 | 0 | 1,212 | | | | - | - | - | | | |
| On-farm labour Use in: | man-day | | | | | | | | | | | | |
| Period 1 | | 29 | 0 | 55 | 19 | 0 | 45 | - | - | - | - | - | - |
| Period 2 | | 29 | 0 | 35 | 21 | 0 | 73 | - | - | - | - | - | - |
| Period 3 | | 32 | 0 | 92 | 28 | 0 | 36 | - | - | - | - | - | - |
| Off-farm labour use for the head of household | man-day | | | | | | | - | - | - | - | - | - |
| Period 1 | | 4 | 400 | 0 | 4 | 400 | 0 | | | - | - | - | - |
| Period 2 | | 4 | 400 | 0 | 4 | 400 | 0 | | | - | - | - | - |
| Period 3 | | 4 | 400 | 0 | 4 | 400 | 0 | | | - | - | - | - |
| Credit | fr.rw | | | | 10,000 | 0 | 10,000 | | | - | - | - | - |
| Nutrition requirements | | | | | | | | | | | | | |
| Calories | $10^3$kcal | 2,672 | -6.2 | 0 | 2,672 | -6.5 | 0 | | | - | - | - | - |
| Proteins | $10^3$g | 43 | 0 | 64 | 43 | 0 | 38 | | | - | - | - | - |

* Values of soil loss and SOC are for a year.
Note: Average exchange rate in 2007: US$1 = 550 Fr.Rw

Table A.3. Economic results of base and alternative scenarios for TEN, MLI&FIL

| | TEN | | MLI | | FIL | |
|---|---|---|---|---|---|---|
| | Base run scenario | Alternative scenario | Base run scenario | Alternative scenario | Base run scenario | Alternative scenario |
| Returns from crops | | | | | | |
| Banana | 5,973 | 722,000 | 905 | 2,238,304 | 5,068 | - |
| Cassava | - | 40,000 | - | 0 | - | - |
| Groundnut | 67 | 40,643 | 377 | 69,554 | 209 | - |
| Bean | - | - | 2,397 | - | 394 | - |
| Sweet potatoes | 2,790 | - | 3,435 | - | 3,420 | - |
| Maize | - | - | - | - | - | - |
| Sorghum | - | | - | - | - | - |
| Cost | | | | | | |
| Seeds | 8,802 | 17,769 | 7,067 | 53,894 | 12,648 | - |
| Pesticides | - | 121,930 | - | 386,040 | - | - |
| Organic fertiliser | - | 27,758 | - | 77,872 | - | - |
| Inorganic fertiliser | - | 2,206 | - | 3,201 | - | - |
| Rent of spray pump | - | 1,756 | - | 4,553 | - | - |
| Transaction costs | - | 106,536 | - | 330,744 | - | - |
| Gross margin | -28 | 471,669 | 47 | 1,512,956 | -3,557 | - |
| Value of self-consumed crops | | | | | | |
| Banana | 68,780 | - | 7,059 | | 37,286 | - |
| Cassava | - | - | - | - | - | - |
| Groundnut | - | 30,587 | - | 32,682 | - | - |
| Bean | 14,946 | - | 46,106 | - | 52,989 | - |
| Sweet potatoes | 48,105 | - | 42,966 | - | 90,357 | - |
| Maize | - | - | 42,906 | - | 23,899 | - |
| Sorghum | 26,492 | 57,156 | 30,852 | 107,156 | 72,424 | - |
| Total | | | | | | |

## Chapter 6

# General discussion

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## 6.1 Introduction

The increasing population in Rwanda puts pressure on arable land, resulting in soil degradation, which often brings about loss of the production capacity and food insecurity. The current farming systems with low inputs aggravate the problem. There is an urgent need to pursue a sustainable agricultural intensification. The overall goal of the research described in this thesis was to make an assessment of technological options and policy incentives that can enhance adoption of sustainable technologies. The goal was pursued in four different steps, which are described in Chapters two to five. Chapter 2 deals with the stratification of farm households. It is known that adoption of sustainable farming practices may vary among farm households because of differences in available resources, technological characteristics, socio-economic environment and bio-physical conditions. This classification is based on available biophysical and farm household data. Chapter 3 deals with modelling representative typical farm household. This results in the intended bio-economic model. In Chapter 4, adapted crop growth simulation models are used to predict crop yields under sustainable land management practices. In the fifth Chapter, the bio-economic model is used to analyse the effects of sustainable land management practices on farm income, food production and soil loss for different types of farm households and to examine the policy options to stimulate adoption of these technologies.

The current Chapter presents and discusses briefly the main findings of the research and draws the main conclusions. This Chapter is organised as follows. In the next section, a critical assessment is made of the methodologies used. Thereafter follow an overview of the contribution, insights and policy implications derived from the results. The Chapter ends with the main conclusions that follow from the findings.

## 6.2 Methodological issues

### 6.2.1 Farm level approach

An assessment of technology options can be done at field, farm, regional, national or global level (Struif Bontkes, 1999). In this research, we used a farm level approach since farmers are the key players of rural development in Rwanda. The farm level is the place where decisions are taken, that directly affect the processes related to sustainable agriculture (e.g. soil erosion, soil fertility, production, income). The heterogeneity of farms with respect to their specificity (soil type, farm size, intensity of use) and the differences in socio-economic characteristics of farmers (family size, education, off-farm opportunities), which may affect adoption of technology also suggest an analysis at farm level. This makes the farm level approach effective and appropriate for exploring the effects of policy incentives towards adoption of technology for different farm types. The major inconvenience of the farm level approach is that the market prices (i.e. input and output prices, wage rates) are exogenous at that level, unlike the aggregated level (i.e. regional, national and global) where mechanisms to control the demand and supply of inputs and outputs can be put in place. Besides, perfect market conditions rarely exist in rural areas of developing countries. Not all products and factors of production can be traded on markets because of the shallow markets among others (Sadoulet and de Janvry, 1995).

### 6.2.2 The use of a bio-economic modelling approach

A bio-economic modelling approach is needed when analysing profitability and sustainability of land at farm-level (Struif Bontkes, 1999; Kruseman, 2000). A bio-economic framework is based on an integration of biophysical and social sciences approaches. The combinatorial approach of biophysical and social sciences is required to provide policy-makers with adequate information about appropriate incentives to induce farmers towards more sustainable land use (Ruben et al., 1998).

In analysing the relationships between agricultural production practices and sustainability, basically two approaches are used: econometric modelling and mathematical programming (Hazell & Norton, 1986 and Weersink et al., 2002). Econometric modelling allows for statistical testing of economic and/or technical relations, while mathematical programming models are systems of equations that replicate farm-level production possibilities and restrictions. The advantage of the econometric approach is that it can link decisions at small-scale level to a large scale level in a statistically consistent manner (Weersink et al., 2002). However, this approach presents some limitations such as the difficulty in getting long time series (panel) which are costly in terms of time and money. Also, an econometric approach cannot deal very well with unprecedented technologies as there are no historical data with regards to the use of new technologies. Given that, the mathematical programming approach is preferred when it is to examine farm-level choices on technology options and effects of policies on farmer choice. Furthermore, complex relationships related to technology choice can more easily be managed with the latter approach. Since the purpose of this research was to assess technology options and determine possible policy incentives for adopting sustainable technologies at farm-level, a mathematical programming approach was used (Chapters 3&5). Hence, several activities, constraints and variables can be added or removed in the model and the effect of these on the farmer choice towards adoption of alternative agricultural activities can be analysed. With a mathematical programming approach, new production techniques can easily be incorporated by means of adding new activities in the model. Therefore, alternative agricultural activities developed in Chapter 4 were tested in the bio-economic model of Chapter 5. Alternative agricultural activities are defined as alternative activities that are technically feasible alternatives, often technological innovations or newly developed cropping practices not yet practiced at wide scale in a region under study (Van Ittersum and Rabbinge, 1997; Hengsdijk and Van Ittersum, 2002).

Alternative agricultural technologies with a focus on sustainability can be analysed on the basis of experiments (Struif Bonttkes, 1999), production functions (Lefer and Blaskovic, 1994) and agro-ecological simulation models (Jacobson et al., 1995; Bouman et al., 1996; Van Ittersum and Donatelli, 2003; Jones et al., 2003). In our study alternative technologies were analysed using crop simulation models because they are less demanding than experiments in terms of time and funds, and better able to deal with heterogeneity than production functions.

The estimated current (Chapter 3) and alternative (Chapter 4) agricultural technologies were incorporated as activities into the mathematical programming model in Chapters 3 and 5, respectively.

In this study, a quadratic programming model (QP-model) was used as mathematical programming model to analyse the sustainability of land productivity because it allows to incorporate risk and uncertainty. Risk due to price and weather fluctuations were considered in this research (Chapters 3&5). Optimization is an important feature since the farmers usually want to maximize their income, utility or minimize costs subject to several constraining factors (Acs, 2006). In this study, it was assumed that farmers maximise a single objective, i.e. utility. However, considering only one objective to capture farmer's behaviour may be too simplistic as farmers may pursue other goals as well. This implies that the modelling approach can lead to results that differ from reality. Besides, farmers do not succeed to manage a farm as optimally like a QP-model, because of various reasons such as poor quality of management and lack of skills. Therefore, it is important to keep in mind all these arguments when analysing the results. Modelling results should be seen as the benchmark performance with respect to the constraints and objectives used and the specificity of the farming system ( Van Calker, 2005).

It is known that adoption of new technology and/or responses to policy incentives may vary among farmers because of differences in socio-economic characteristics (De Graaff, 1996; Kobrich et al, 2003; Asfaw and Adamassie, 2004). Farms are not homogenous. In Chapter 2, maximum homogeneity within a type of farm household and maximum heterogeneity between types of farm households were obtained using two multivariate techniques sequentially, Principal Component Analysis and Cluster Analysis. Typifying farm households using qualitative methods such as a 'rapid rural appraisal' (Kobrich et al., 2003) have been discarded of use in this research since they tend to equate types of farms with geographical area, when in fact geographical areas cannot exhibit great diversity.

The quadratic programming model developed in Chapter 3 was used to model how different types of farm households obtained from Chapter 2 are responding to alternative agricultural activities of Chapter 4 and policy incentives towards these technologies in Chapter 5.

## 6.3 Contribution, insights and policy implications

One of the pillars of the Rwanda national poverty reduction program is the plan to transform agriculture (GoR, 2007b). Undertaking the shift from current farming with low inputs to a crop intensification programme (CIP) as a means of making a contribution to poverty eradication requires an increasing of sustainable productivity and profitability (Musoni, 2011). However, the transformation of agriculture towards a sustainable agricultural intensification is highly dependent on several endogenous and exogenous factors in the farming system of Rwanda.

This PhD research has provided several contributions and insights into the possibilities of transforming agriculture in Rwanda at farm level towards more intensive and at the same time sustainable farming systems.

The current farming system with low inputs coupled with an overexploitation of land due to land scarcity and high population density leads to problems of land degradation and low and declining agricultural productivity and consequently to food insecurity.  Chapter 3 enhanced the insight on the status of food security into the current farming in the face of high population density, and its consequences on land degradation. Chapter 3 showed that with more people,  having less land, food security cannot be achieved and that soil loss has a high impact at least on marginal land.  Households with 8 to 10 members and a farm size of 0.5 ha to 0.7 ha are not able to maintain the food security status. However,  a household of 5 members with a minimum of 0.5 ha can satisfy the food requirements while soil loss has relatively little economic impact on farmer wealth. Furthermore, Chapter 3 emphasized the fact that current farming is focussed on subsistence and that the majority of food production is self-consumed. About 88% of the land was devoted to food production for home consumption, while the rest was either used for producing marketed food or left uncultivated. Soil loss, risks due to stochastic weather and prices were key factors in maintaining the subsistence feature of farming.

The current farming system could be improved by introducing alternative agricultural technologies that lead to higher crop yields and better protection of soil. These alternative technologies might prove to increase crop yields, while maintaining soil organic matter and reducing soil erosion. Chapter 4 has quantified alternative agricultural activities in the scope of the biophysical environment of the study' area and under sustainable land management. The latter was based on a combinatorial approach of using organic and inorganic fertiliser. It has been acknowledged that organic and inorganic fertilisers cannot be substituted entirely by one another and are both required for sustainable crop production (Buresh et al., 1997;  Vanlauwe et al., 2002). Organic fertiliser of different qualities combined with chemical fertiliser revealed crop yields that, which are distinctively higher than the yields under low inputs and current practices. However, the different qualities of green manure combined with inorganic fertiliser affected the crop yields differently (Chapter 4). Raemaeckers (2001) highlighted that crop yields may depend on moderate and well distributed rainfall (e.g. beans). Chapter 4 confirmed that if a season has a high amount of, but not well distributed rainfall, especially during its most sensitive development phase (i.e. vegetative growth) crop yields might be lowered. However, an appropriate sowing date may improve the situation.

A major concern with alternative agricultural technologies is: how to induce farmers to adopt them? Policy incentives are critical to transfer crop management technology (Byerlee, 1994). Several studies have underlined the heterogeneity of farm households with regards to the adoption of new technology even within a small geographic area (i.e. village). Furthermore, adoption varies among farm households based on their socio-economic characteristics (De Graaff, 1996; Kobrich et al, 2003; Asfaw and Adamassie, 2004). Therefore, relevant policy incentives should target a homogenous group of farm households for the effectiveness of adoption. Chapter 2 showed that factors such as gender, age, literacy, level of education, off-farm activity, size of the household, tenure and farm size are significantly important in differentiating typical farm households. Chapter 5 revealed that young and educated male heads of households are more likely to fully adopt sustainable technologies. Farmers classified in this cluster have relatively more economic options, which allows them to use technologies requiring more capital. In a study conducted in Ethiopia Asfaw and Adamassie (2004) underlined that being a young and educated farmer facilitates a fast adoption of new technology which requires information and an effective combination of inputs. Though sustainable technologies could improve the farm income of young and educated male headed households, an additional policy intervention such as subsidy on inputs would permit a higher level adoption of these technologies (Chapter 5). The farmers that were classified into the clusters female headed and tenant (Chapter 2) might be expected to be vulnerable with regards to adoption of sustainable technologies. It has often been argued that women are deprived and discriminated, with limited access to resources (World Bank, 2007), while tenant farmers have often been considered as very poor (Brugere and Lingard, 2003). Chapter 5 showed that these two farm household types partially adopted sustainable technologies. However, a full adoption should be expected if more credit and off-farm employment could reach the female heads of households and tenant farm households. Off-farm employment is important since it is viewed as an alternative way of overcoming capital constraints, especially where the credit markets are inaccessible. Owusu et al. ( 2010) emphasized that participation in off-farm activities exerts a positive and statistically significant effect on farm household and income. Farmers identified as illiterate and fulltime had large families, relatively large farms and few opportunities to participate in off-farm activities (Chapter 2). Chapter 5 revealed that for these farmers adoption of sustainable technologies was very much restricted by capital constraints. This situation could be reversed if illiterate and fulltime farm household would get an increase of 250% and 350% of credit and off-farm activities, respectively.

The bio-economic farm model and its applications developed in this study give more insights into the possibilities of transforming the current farming system towards more sustainable farming. In addition, policy-makers get an idea of suitable policy interventions to enhance a sustainable agricultural productivity at farm level.

## 6.4 Main conclusions

The major conclusions of this thesis can be summarized as follows:

1. The heterogeneity of farm households that underlie adoption of new technology is reflected by the five farm household types identified by means of multivariate statistical techniques such as principal Component Analysis and Cluster Analysis (Chapter 2).

2. With current agricultural technologies a higher availability of good land can increase farm income, whereas a higher availability of marginal land has only a slight impact on income in eastern province of Rwanda (Chapter 3).

3. With current agricultural technologies smaller farm households leads to lesser soil erosion and more food for each household, with larger households and less land, food security cannot be maintained and land degradation becomes worse (Chapter 3).

4. The crop yields under alternative agricultural technologies, assessed with the crop simulation models, with combined use of organic and inorganic fertilisers, are significantly higher than the actual yields under current small-scale farming (Chapter 4).

5. Different qualities of organic fertiliser combined with inorganic fertiliser affect crop yields differently. Green manure *Tithonia diversifolia* combined with Diammonium phosphate appeared to have the largest effect on crop yields (Chapter 4).

6. The investigated alternative agricultural technologies ensure a more intensive crop production, a better food security, and a higher farm income. Moreover, it prevents soil loss and improves soil quality for the farm households who adopt them (Chapter 5).

7. Off-farm employment stimulation and provision of credit will have a positive impact on adoption of alternative agricultural technologies for households with small farms and low off-farm opportunities, while subsidies on inputs will substantially improve adoption for young and educated farm household (Chapter 5).

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# Summary

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**Summary**

The increasing population in Rwanda puts pressure on arable land, resulting in soil degradation, which often brings about loss of the production capacity and food insecurity. The current farming systems with low inputs aggravate the problem. There is an urgent need to pursue a sustainable agricultural intensification. The overall goal of the research described in this thesis was to make an assessment of technology options and policy incentives that can enhance sustainable farming in Rwanda to improve food security and raise cash output. The goal was pursued in four different steps, which are described in Chapters two to five.

Chapter 2 typified farm households in Umutara province based on socio-economic factors influencing the adoption of new technology. A multivariate analysis approach that combines Principal Component Analysis and Cluster Analysis was used to clearly identify five types of farm households and their socio-economic characteristics. The main differences between the five farm types relate to gender, age, education, risk perception, risk attitude, labour availability, land tenure and income. The five farm types are characterized by respectively having a female head (26% of the farms), being a tenant (7%), having a male and literate head (32%), having a male illiterate head with no off-farm activities (18%), and being a large farm with livestock (17%). The respective farm types appeared to have adopted different types of sustainable technologies to a limited extent. Female-headed households adopted the use of compost and green manure. Young male literate farmers were the only ones using chemical fertilizers. Illiterate and full-time farmers applied fallow, manure and erosion control measures to maintain soil fertility. The use of improved livestock is adopted by large farms.

The objective of Chapter 3 was to develop a bio-economic model capable of analysing the impacts of soil erosion, family planning and land consolidation policies on food security in Rwanda, apply this for one typical farm household. The developed model was a quadratic programming model including risk and whose objective function was to maximise utility.

Calculations with the bio-economic model showed that a higher availability of good farm land would increase the farm income. Additionally, preserving soils against erosion and reducing risk would allow for using more marginal land which would increase food production for home consumption and for the market. Increasing the opportunities for off-farm employment can also increase farm household income. The outcomes of the model supported the Rwanda policy on family planning, while the policy on land consolidation is not endorsed.

The low agricultural productivity of Rwanda reflects the poor soil fertility status due to a low organic matter content and a high soil acidity that characterises a large part of the country. Experimental trials have shown that a combined use of organic and inorganic fertilisers can increase crop yield. However, there are no guidelines for combined nutrients of different sources and qualities. Crop growth models can assist in the evaluation of the integration of organic and inorganic fertilisers. The Decision Support System for Agrotechnology Transfer (DSSAT) presents a collection of such crop models. The objective of Chapter 4 was to assess alternative production activities through yield prediction of several crops under combined use of organic and inorganic fertilisers on Oxisols and Inceptisols in eastern Rwanda and to determine the best fertility management options. The DSSAT (Decision Support System for Agrotechnology Transfer) crop models were used to quantify the alternative production activities testing different treatments. The simulation of crop yields showed that predicted crop yields were distinctly higher than the actual yields for the current small-scale farming practices that are common in the region. The predicted yields for beans, groundnuts and cassava were approximately the same for all treatments, while the combined application of *Tithonia diversifolia* and Diammonium phosphate appeared to predict higher yields for maize and sorghum. Yield prediction for all crops was higher on the Inceptisols than on the Oxisols due to the better chemical and physical conditions of Inceptisols. This is in line with reality.

Although technical options for sustainable land use can be available, the major concern is to induce farmers to adopt these technologies. The objectives of Chapter 5 were to assess the potential impacts of the alternative agricultural technologies on income, food production and soil loss for four types of farm households, and to assess policies that could induce adoption of these technologies. Using the model developed in Chapter 2, model results showed that these alternative agricultural technologies will clearly enhance food production (after a learning period) and income for all farm household types except the household with the largest farm for which cash at the beginning of the season is too restricted to switch to the new technologies. The outcomes of the model also revealed that the alternative technologies will prevent soil loss and improve soil quality. Off-farm employment policy will have a high impact on adoption among households with small farms and less off-farm opportunities because it provides cash that is needed to adopt the new technologies. Subsidies on inputs will substantially improve adoption of the alternative technologies among literate farm households. Overall, the provision of credit and the availability of off-farm activities have emerged as the policies, that are most likely to enhance adoption of the alternative technologies in all the farm households.

## Samenvatting

De snel groeiende bevolking in Rwanda oefent druk uit op de landbouwgronden, wat leidt tot landdegradatie en vaak een verlies van productiecapaciteit en voedselonzekerheid tot gevolg heeft. De huidige landbouwbedrijfssystemen met weinig inputs verergeren het probleem. Er is dringend behoefte aan een duurzame intensivering van de landbouw. Het uiteindelijke doel van het onderzoek, zoals beschreven in dit proefschrift, was om technologische mogelijkheden en beleidsmaatregelen te bekijken die duurzame landbouw in Rwanda kunnen bevorderen en voedselzekerheid en inkomsten kunnen vergroten. Voor het bereiken van deze doelstelling werden vier stappen ondernomen, die achtereenvolgens beschreven worden in de hoofdstukken 2 tot 5.

In hoofdstuk 2 worden diverse landbouwbedrijfstypen onderscheiden, op basis van sociaaleconomische factoren, die de adoptie van nieuwe technologie beïnvloeden. Een "multivariate analyse" benadering met gebruik van Principal Component Analyse en Cluster Analyse is gebruikt om vijf kenmerkende bedrijfstypes te identificeren, met hun sociaaleconomische karakteristieken. De belangrijkste verschillen tussen de vijf types hangen samen met gender, leeftijd, onderwijs, risicoperceptie, houding t.o.v. risico, beschikbaarheid van arbeid, landeigendom en inkomen. De vijf onderscheiden bedrijfstypes kunnen respectievelijk omschreven worden als: geleid door een vrouw (26 % van de bedrijven), pachter (7 %), geleid door een geletterde man ( 32 %), geleid door een ongeletterde man zonder activiteiten buiten het bedrijf (18 %), en als relatief groot bedrijf met vee (17%). De afzonderlijke bedrijfstypes bleken in beperkte mate verschillende soorten duurzame technologieën geadopteerd te hebben. De door vrouwen geleide bedrijven hebben het gebruik van compost en groenbemesters geadopteerd. Jonge, geletterde mannen zijn de enigen die kunstmest gebruiken. Ongeletterde en voltijdse boeren gebruiken braak, dierlijke mest en

erosiebestrijdingsmaatregelen om de bodemvruchtbaarheid in stand te houden. En de grotere bedrijven maken gebruik van verbeterde veerassen.

Het doel van hoofdstuk 3 was om een bio-economisch model te ontwikkelen dat de effecten van bodemerosie, gezinsplanning en beleid t.a.v. landconsolidatie op voedsel zekerheid in Rwanda kan bepalen, en om dat model toe te passen voor één kenmerkend bedrijfshuishouden. Een kwadratisch programmeringsmodel is ontwikkeld, dat ook risico meeneemt, en dat als doelfunctie nutsmaximalisatie heeft. Berekeningen met het bio-economisch model laten zien dat een ruimere beschikbaarheid van land tot een hoger bedrijfsinkomen leidt. Daarnaast zullen erosiebestrijdingsmaatregelen en een verminderd risico het mogelijk maken meer marginaal land in gebruik te nemen en zodoende de voedselproductie voor zelfvoorziening en voor de markt te vergroten. Het verruimen van de mogelijkheden om buiten het landbouwbedrijf te werken kan ook het huishoudinkomen vergroten. De uitkomsten van het model onderschrijven het Rwandese beleid t.a.v. gezinsplanning, maar niet het beleid t.a.v. landconsolidatie.

De lage landbouwproductiviteit is een weerspiegeling van de lage bodemvruchtbaarheid als gevolg van een laag organische-stofgehalte en een hoge bodemzuurgraad, die karakteristiek zijn voor een groot deel van het land. Experimenten hebben aangetoond dat een combinatie van organische en anorganische meststoffen gewasopbrengsten kan verhogen. Er zijn echter geen richtlijnen voor de combinatie van nutriënten van verschillende oorsprong en kwaliteit. Gewasgroeimodellen kunnen behulpzaam zijn bij de evaluatie van geïntegreerde organische en anorganische bemesting.

Het “Decisoir Support System For Agrotechnology Transfer (DSSAT)” biedt een verzameling van zulke gewasmodellen. Het doel van hoofdstuk 4 was om alternatieve productieactiviteiten te vergelijken d.m.v. opbrengstvoorspellingen voor een aantal gewassen bij een gecombineerd gebruik van organische en anorganische mest op Oxisol en Inceptisol gronden in het oosten van Rwanda, en dan de beste bemesting optie te bepalen. De DDSAT gewasmodellen werden gebruikt om alternatieve productieactiviteiten te kwantificeren bij gebruik van verschillende bemestingscombinaties. De simulaties van gewasopbrengsten laten zien dat de voorspelde gewasopbrengsten met bemestingscombinaties aanzienlijk hoger waren dan de opbrengsten van de huidige kleinschalige landbouwmethodes in de regio. De voorspelde opbrengsten voor bonen, aardnoten en cassave lagen ongeveer op hetzelfde niveau voor alle bemestingscombinaties, terwijl de combinatie van *Tithonia diversifolia* als groenbemester met Di-ammonium fosfaat hogere opbrengsten voor mais en sorghum voorspelde. De opbrengstvoorspelling was hoger voor Inceptisols dan voor Oxisols vanwege de betere chemische en fysische condities. Dat strookt met de werkelijkheid.

Technische opties voor duurzaam landgebruik kunnen aanwezig zijn, maar het gaat er vooral om dat boeren er toe over gaan deze technologieën te adopteren. Het doel van hoofdstuk 5 is om na te gaan wat de potentiële effecten van de alternatieve landbouw technologieën zijn op inkomen, voedselproductie en bodemverlies voor vier verschillende bedrijfstypes, en om te zien welk beleid de adoptie van deze technologieën kan bevorderen.

De resultaten met het model, zoals dat ontwikkeld is in hoofdstuk 2, laten zien dat deze alternatieve landbouw technologieën (na een leerperiode) de voedselproductie en het inkomen voor alle bedrijfstypes duidelijk verhogen, met uitzondering van het voltijds ongeletterde type, voor welk geldgebrek aan het begin van het seizoen een overgang naar nieuwe technologieën onmogelijk maakt.

De modeluitkomsten tonen ook aan dat de alternatieve technologieën bodemverlies tegengaan en bodemkwaliteit verbeteren. Beleid t.a.v. werkgelegenheid buiten het bedrijf heeft veel effect op huishoudens met kleine bedrijven en weinig werk buiten het bedrijf, omdat het cash inkomen genereert dat nodig is voor deze nieuwe technologieën. Subsidies op inputs zullen de adoptie van alternatieve technologieën onder geletterde boeren verbeteren. In het algemeen zijn kredietverschaffing en beschikbaarheid van werkgelegenheid buiten de landbouw waarschijnlijk de beleidsmaatregelen die de adoptie van alternatieve technologieën het beste kunnen verhogen.

## Publications

### Refereed scientific papers

J.C. Bidogeza, P.B.M. Berentsen , J. De Graaff and A.G.J.M. Oude Lansink (2009). Farm Household Typology for Umutara Province in Rwanda. *Food Security: The Science, Sociology, Economics of Food Production and Access to Food*, 1(3): 321 – 335.

J.C. Bidogeza, P.B.M. Berentsen , J. De Graaff and A.G.J.M. Oude Lansink (2010). Bio-Economic Modelling of the Influence of Family Planning, Land Consolidation and Soil Erosion on Farm Production and Food Security in Rwanda: Under review *Agricultural Systems.*

J.C. Bidogeza, G.Hoogenboom, P.B.M. Berentsen , J. De Graaff and A.G.J.M. Oude Lansink (2010). Application of DSSAT crop models to generate altenative production activities under combined use of organic-inorganic nutrients in Rwanda. Submitted to *Journal of Agricultural Science.*

J.C. Bidogeza, P.B.M. Berentsen , J. De Graaff and A.G.J.M. Oude Lansink (2011). Ex-ante assessment of policies for the adoption of alternative agricultural activities to ensure food security and raise income of farm households in eastern province of Rwanda. Submitted to *Journal of Agricultural Economics.*

### Presentations papers

J.C. Bidogeza, P.B.M. Berentsen , J. De Graaff and A.G.J.M. Oude Lansink ( May 2009). The influence of family planning and land consolidation on farm production and food security: a bio-economic modelling approach. Mansholt Graduate School – PhD Day, Wageningen University , Wageningen, The Netherlands.

J.C. Bidogeza, G. Hoogeboom, P.B.M. Berentsen , J. De Graaff and A.G.J.M. Oude Lansink (February 2009). Application of DSSAT Crop Models to Simulate Crop Yields Under Combined Use of Organic-Inorganic Nutrients in Rwanda. Seminar at the Department of Agricultural and Biological Engineering, University of Georgia, USA.

J.C. Bidogeza, P.B.M. Berentsen , J. De Graaff and A.G.J.M. Oude Lansink (August 2007). Multivariate Typology of Farm Households Based On Socio-Economic Characteristics Explaining Adoption of New Technology in Rwanda . The 2nd International Conference of African Agricultural Economists, Accra, Ghana.

J.C. Bidogeza, P.B.M., Berentsen , J. De Graaff and A.G.J.M. Oude Lansink ( May 2007). Representative Bioeconomic Household Models in Rwanda. Mansholt Graduate School symposia, Social Sciences applied to Agrifood Systems and Rural Development ,Wageningen University, Wageningen, The Netherlands.

## CURRICULUM VITAE

Jean-claude Bidogeza was born on 24th September 1970 in Bujumbura, Burundi. He finished his secondary education at Athenée de Bujumbura (now Lycée Rohero) in 1990. In the same year he began his studies at the Faculty of Agronomy, University of Burundi. In 1996 he obtained his engineers degree in agronomy, majoring in animal production. In 1997 he started his career in Rwanda as a consultant in the Ministry of Family and Gender. In 1998-2001, he was a an assistant-lecturer at the High Institute of Agricultural and Animal Husbandry (ISAE) in Rwanda. In 2001 he was granted a scholarship by World Bank to study a Master of Science programme in management of physical land resources at the University of Ghent, Belgium. In 2003 he obtained his Master of Science degree with distinction. His master's thesis was entitled 'Application of qualitative and quantitative tools to assess land productivity in Umutara Province, Rwanda'. In 2003-2005 he was a lecturer and head of Agroforestry Department at ISAE. 15th of September 2005, Jean-claude started his PhD research in Business Economics at Wageningen University, Netherlands. In 2009 during the course of his PhD, he has been a visiting scientist at the department of biological and agricultural engineering, University of Georgia (USA).
From April 2011, he is an international consultant working with the United Nations Development Programme – Regional Bureau for Africa (UNDP-RBA). His work is focused on food security issues. Jean-claude and his family are living in Nairobi (Kenya).

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| Description | Institute / Department | Year | ECTS* |
|---|---|---|---|
| **Courses:** | | | |
| Mansholt Introduction course | Wageningen Graduate School of Social Sciences | 2005 | 1 |
| Information Literacy | Wageningen University | 2005 | 0.6 |
| Project and Time Management | Wageningen University | 2005 | 1.5 |
| Business Economics Seminars | Business Economics Group | 2005-2010 | 4 |
| Multi Criteria Decision Making in Agriculture: Theory and Applications | Wageningen Graduate School of Social Sciences | 2005 | 2 |
| Techniques for Writing and Presenting Scientific Papers | Wageningen University | 2006 | 1.2 |
| Advanced Agricultural Business Economics | Wageningen University | 2006 | 6 |
| Policy Evaluation Methodology | Graduate Schools SENSE-WIMEK | 2006 | 4 |
| Theory & Practice of Efficiency and Productivity Measures; Non-parametric approach | Wageningen Graduate School of Social Sciences | 2006 | 1.5 |
| Theory & Practice of Efficiency and Productivity Measures; Parametric approach | Wageningen Graduate School of Social Sciences | 2006 | 1.5 |
| Quantitative Analysis of Land Use Systems (QUALUS) | Wageningen University | 2006 | 4 |
| Quantitative Data Analysis : Multivariate Techniques | Graduate School PE&RC | 2007 | 1.5 |
| Advanced Statistics | Graduate School PE&RC | 2007 | 1.5 |
| Decision Support Systems for Agrotechnology Transfer (DSSAT) | Georgia University (USA) | 2009 | 6 |
| Using Voice in Public Presentation | Business Economic Group/Operation Research Group | 2011 | 0.5 |
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| PhD Day, Wageningen, Netherlands | | 2007 | |
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| **Total (minimum 30 ECTS)** | | | **39.8** |

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