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Improving the existing farming systems towards a climate smart agriculture in Musanze district of Rwanda

Stephanie Uzamukunda

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Stephanie Uzamukunda

Supervisor: Professor Erik Steen Jensen,
Swedish University of Agricultural Sciences,
Department of Biosystems and Technology

Examiner: Dr. Georg Carlsson,
Swedish University of Agricultural Sciences,
Department of Biosystems and Technology

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Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Faculty of Landscape Architecture,
Horticulture and Crop Production Science
Department of Work Science, Business Economics
and Environmental Psychology

Foreword

Coming from a developing country, Rwanda, facing the problem of food security and with a background in crop production and horticulture, I had in mind an objective of increasing agricultural production to feed our suffering people. I identified nature and its resources as something to be exploited by human for their well-being. For this, using all the possibilities to maximize its exploitation for food production was a good option for me. I could not project far to see myself included in nature and that its maintenance is also the maintenance of human. I couldn't imagine to which degree the overexploitation of natural resources to satisfy the current production has negative impacts on future production. However, I had seen people resisting to policies and programs inaugurated in Rwanda aiming at increasing agricultural production through the promotion of monoculture system, due to its associated weaknesses mainly the lack of diversified food and the reduction of crop rotation practice followed by crop destruction due to extreme weather events such as heavy rains and drought. I couldn't make a sustainability analysis to help improve this situation.

With the Agroecology program, I came out to reshape my thinking and I came out to make a critical analysis of sustainability by including all its inseparable aspects: society, economy and environment. I also understand the role of participation by involving all stakeholders in decision making towards a sustainable production and development. For this, after reviewing the farming systems in Rwanda particularly in Musanze district, I suggested a farming system which can help to boost the agricultural production without causing severe environmental damages.

Stephanie Uzamukunda

May, 2015

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May Almight God bless you all!

Stephanie Uzamukunda

May, 2015

Abstract

From the older mixed intercropping which has not been able to produce higher yields, to the monoculture system currently promoted by the government of Rwanda and which has helped to increase the yield of the prioritized crops, agriculture production has continued to be challenged by climate change where droughts, heavy rains, severe soil erosions, strong winds, pests and diseases have reduced significantly the production in some of the affected areas. It is for this reason that this review was done particularly on Musanze district, an areas which is considered as the food basket of Rwanda for its high agricultural production, but which is highly affected by torrential rains from the Volcano National Park, followed by floods and landslides, which in turn causes severe crop destruction and soil erosion; in order to help to suggest another farming system which can help to lead to a climate-smart agriculture.

While the population continues to grow, putting much pressure on land, both systems have failed to adapt to climate change in order to satisfy food needs with low environmental damages, and the future climate change scenarios predict that the situation may become worse in the coming decades. That is why a complex mixed cropping system is suggested in Musanze district in order to diversify food products hence leading to food security, help to control the soil erosion, a major challenging issue faced by farmers and reduce other socio-economic and environmental damages resulting from heavy rains, floods and landslides. This study suggests two options of mixed cropping: (1) strip cropping inside the farm together with trees/shrubs and/or anti-erosive crops contouring the farm; or (2) row intercropping inside the farm with trees/shrubs and/or anti-erosive crops contouring the farm.

Its implementation will help to reach food security, to adapt to climate change while trying to reduce greenhouse gas emission. For this reason, it requires governmental commitment towards farmers' needs and involving them in decision making, but also to change from the only economic focus to the other aspects of sustainability: social and environment in order to have enjoyable life both for current and the future generations.

Keywords: Climate change, climate-smart agriculture, future scenario, farming systems, complex mixed cropping, sustainability, imihigo, Musanze district, Rwanda.

List of abbreviation

CA: Conservation Agriculture

CIP: Crop Intensification Program

CMC: Complex Mixed Cropping

CNRM- CM 3: National Meteorological Research Center–Climate Model 3

CSA: Climate-smart agriculture

CSIRO Mark3: Commonwealth Scientific and Industrial Research Organization Mark 3

GDP: Gross Domestic Product

DRC: Democratic Republic of Congo

ECHAM 5: fifth-generation climate model developed at the Max Planck Institute for Meteorology (Hamburg)

FAO: Food and Agriculture Organization of the United Nations

GCM: General Circulation Models

GHG: Greenhouse gas

LER: Land Equivalent Ratio

LSF: Large Scale Farmers

MIROC: Model for International Research On Climate

MIDIMAR: Ministry of Disaster Management and Refugee Affairs

NISR: National Institute of Statistics of Rwanda

REMA: Rwanda Environment Management Authority

SAFA: Sustainability Assessment of Food and Agriculture

SSF: Small Scale Farmers

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1. Introduction

The global population is expected to reach 9 billion in 2050 (IPCC, 2007; Foley, 2011) which will also require probably to double the current food production in order to meet the demand (Foley, 2011). However this increase is supposed to be achieved while there is a big challenging issue of climate change. The global warming is also predicted to increase by various scenarios in the same period. The changes in temperature and precipitation and their respective effects will make agricultural production more vulnerable as the overall impact of climate change on agriculture is predicted to be negative (IPCC, 2007).

The other time humans were put under pressure of producing much food for the global population is after the Second World War. This was achieved through the green revolution. It was established in the 1960's in order to solve the problem of food crisis. The global food production was not coping with the world's population increase (Khush, 1999 & Herder *et al*, 2010). The development of technology and the monocropping system helped to reach higher yields. According to different authors among others Khush (1999), Lynch (2007) and Singh (2000), the success of the green revolution resulted from the development of high yielding varieties, synthetic fertilizers and pesticides, development of irrigation facilities and the political willingness. These led to increased agricultural production, food sufficiency and economical improvement (Khush, 1999; Herder, *et al*, 2010; Lynch, 2007; Singh, 2000).

According to Gliessman (2007), the conventional farming has two goals which are the "maximization of production and maximization of profit" (Gliessman 2007, pp. 3). Farmers' need to achieve these goals has contributed to climate change and variability, severe damages of the environment and disturbance of the ecosystem services on which human and other livings depend upon (Millennium Ecosystem Assessment, 2005). Following are some of the examples of damages caused by the green revolution: Water and environmental pollution, decrease in soil fertility, soil losses due to erosion, soil salinity and compaction, nutrients leaching, decline in soil organic matter content, pests and diseases breakdown, drought and floods (Singh, 2000; Herder, *et al*, 2010; Millennium Ecosystem services, 2005). Due to unsustainable farming systems and practices, agriculture has also contributed to the increase of the greenhouse gas emission (International Food Policy Research Institute, 2009; Waithaka, et al., 2013) which in turn leads to global warming, increased precipitation, and seasonal variation across the world (International Food Policy Research Institute, 2009; Waithaka, *et al*., 2013; Bogdanski, 2012).

Since the green revolution, agricultural production has improved significantly in different parts of the world with an increase of 2.2% during the period of 1997 to 2007 per year globally (Beddington, *et al*., 2012). Despite this great achievement in agriculture, several hundred millions of people are still suffering from food insecurity worldwide.

The current call to increase food production for an increasing population in the coming decades requires a connection of food production and food systems with climate change.

1.1. Climate change

The IPCC defines climate change as "a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity" (IPCC, 2007). Following are the natural processes that influence climate change: solar energy (reaching or reflected by the earth), volcanic eruptions and greenhouse gases concentration (United States Environmental Protection Agency, 2014). These factors contribute to climate change without the human influence. However, since the industrialization period, human activities are mainly the driving force of climate change (IPCC, 2007; Rockström, *et al*., 2009; Steffen, *et al*., 2004). Humans contribute a lot to the increasing greenhouse gases concentration. Greenhouse gases emissions are the key factor to climate change contributing to global temperature increases and global warming (IPCC, 2007; United States Environmental Protection Agency, 2014). The major greenhouse gases (see figure 1, A) are *c*arbon dioxide (CO_2), methane(CH_4) and nitrous oxide (N_2O). Other greenhouse gases include water vapor, ozone (O_3), and others (United States Environmental Protection Agency, 2014).

Human activities has contributed up to 70% of the greenhouse gases increase during the period between 1970 to 2004 (IPCC, 2007) with CO2 at all places taking a large contribution of 80% alone (IPCC, 2007; United States Environmental Protection Agency, 2014). The CO2 is generally generated by high fossil fuel use together with the change in land use (deforestation and reforestation, desertification, etc) while CH4 and N2O are mainly generated by agricultural activities (IPCC, 2007). It is proved that human contribution to CO2 emission is more than 135 times the contribution of volcanoes eruption every year (United States Environmental Protection Agency, 2014). Agriculture contributes itself to about 14% to greenhouse gas emission (IPCC, 2007; IFAD, 2011; see also figure 1, B) where Asia, America and Africa are the most contributors, producing 42.7%, 25.2% and 14% respectively

(FAOSTAT, 2015). The key sources of this emission from agriculture (see figure 1,D) are: enteric fermentation, manure handling, chemical fertilizers, rice cultivation, soils and crop residues management (IPCC, 2007; United States Environmental Protection Agency, 2014; FAOSTAT, 2015).

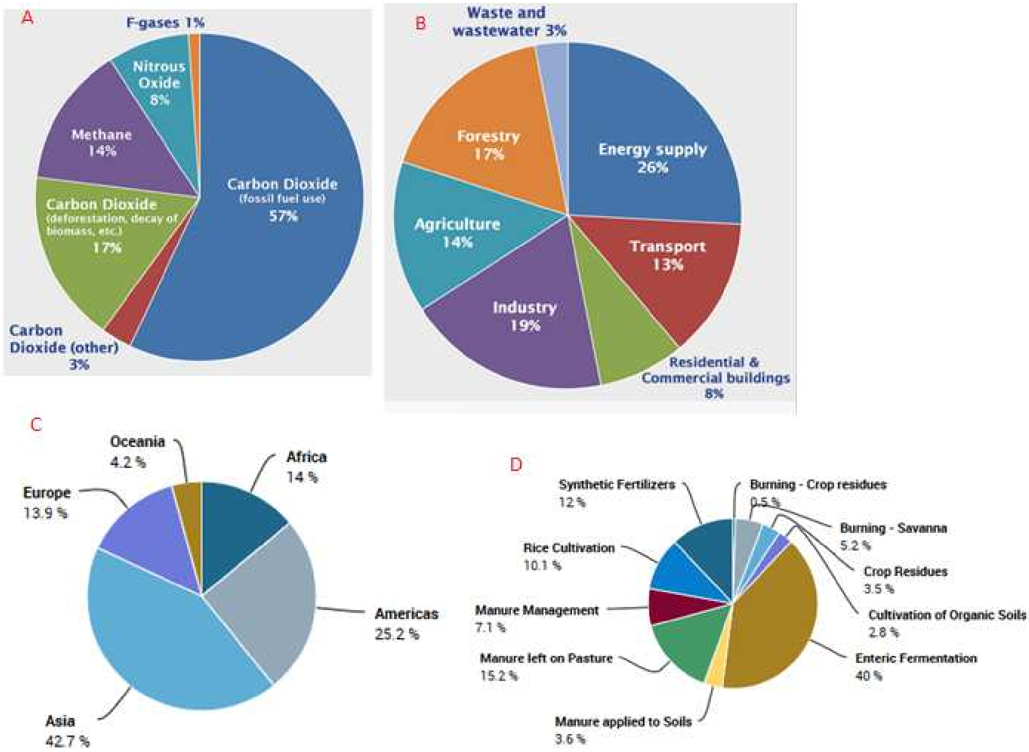

Figure 1: Global greenhouse gas emission : A) emission by gas where F-gases means Fluorinated gases and are human induced only; B) emission by source; C) emission from agriculture by continents (averages between 1990 to 2012) D) agricultural emission by sectors (averages between 1990 to 2012). Sources: A and B (IPCC, 2007; United States Environmental Protection Agency, 2014); C and D (FAOSTAT, 2015).

The high dependency on fossil fuel, industrialization and agricultural activities have mainly caused drastic impact on natural processes on which human depend upon (Rockström, *et al*., 2009; Steffen, *et al*., 2004) and accelerate the global warming. Indicators of the global warming are observable in different parts of the world. It is for example the snow and ice melting, sea level rising, global temperature increases, extreme weather events such as severe droughts, storms, winds and heavy rains, (IPCC, 2007).

All these issues have led to high vulnerability of natural processes. Figure 2 shows the planetary boundaries with a safe operating space (green colored inside) made in 2009 by Röckstrom and colleagues. Three of the nine processes in the figure had already exceeded their limits. These were climate change, nitrogen cycle and biodiversity. But also, the ocean acidification, phosphorous cycle, change in land use and global fresh water use were about to cross their safe space of use (Rockström, *et al*., 2009) if no measures of well management were taken.

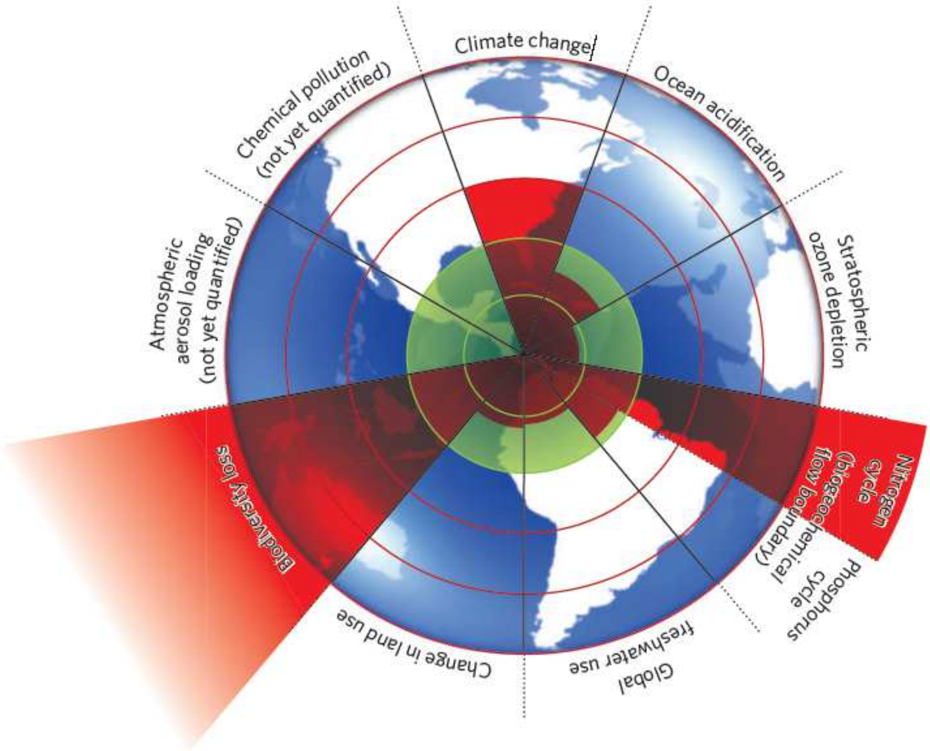

Figure 2: Planetary boundaries with its three already exceeded processes (Rockström, *et al*., 2009).

Six years later (in 2015), changes (including new names of boundaries such as *land-system* change replacing land use change; *biosphere integrity* replacing biodiversity loss and *introduction of novel entities* replacing chemical pollution) and new quantifications have happened and currently, on the previous three boundaries crossed, a forth one is also transgressed: land-system change. Another component of the biogeochemical flows: Phosphorus is also transgressed (Stockholm Resilience Center, 2015). Changes in land use, agricultural farming systems and practices such as chemical fertilizers and pesticides manufacturing and use, wildfires, etc play a great role in crossing these limits by contributing to global warming, influencing the rate of species extinction and accelerating the ocean acidification (Rockström, *et al*., 2009; Steffen, *et al*., 2004).

Although agriculture has a significant impact on climate change, this last also highly affects agriculture. The agriculture sector is highly vulnerable to variation and changes of climate. Temperatures and precipitations which mainly determine the climate of a given region (IPCC, 2007) play also a major role in crop distribution in different parts of the earth (Beddington, *et al*., 2012). With the global temperature increase in the future, climate change will affect agriculture in different ways. For example, some crops will be introduced or grown in regions where they could not grow while others will fail to grow leading to crop yield loss or gain according to a region (IPCC, 2007; Beddington, *et al*., 2012). Increased temperatures reduce crop yield and promote the spread of new pests and diseases (Waithaka, *et al*., 2013) but also reduced precipitations lead to crop failure and reduction of productivity (Nelson, *et al*., 2009; Beddington, *et al*., 2012). The impact of climate change on crop yield will then influence production, prices and consumption which in turn have an impact on human calorie consumption and the rate of malnutrition (Nelson, *et al*., 2009). This will make the world's first millennium goal of eradicating hunger and extreme poverty unachievable in different countries mainly in the developing world (Nelson, *et al*., 2010) where agriculture is the main source of income for most of the people but also where food security, poverty and malnutrition are serious problems (Ziervogel & Zermoglio, 2009; Beddington, *et al*., 2012; Waithaka, *et al*., 2013).

1.2. Climate change scenarios

Due to human activities, climate change is expected to be worse than it is today. Different scenarios have already been developed showing how the future will be looking like. As agriculture influences and is influenced by several factors, the scenarios also combines different models in predicting the future. Widely used to predict temperatures and precipitations are general circulation models (GCM) showing the chemical and physical state of the atmosphere and its relationship with the ocean and land surface (IPCC, 2007). IPCC (2007) provides details of these models. Two of these models give two extremes in temperatures and precipitations: (1) CSIRO Mark3 is a climate model developed at the "Australia Commonwealth Scientific and Industrial Research Organization" (CSRO) which predict lower temperatures and precipitations in comparison with others; while (2) MIROC 3.2 is a "Model for Interdisciplinary Research On Climate (MIROC), developed at the University of Tokyo Center for Climate System Research" predicting higher temperatures and higher precipitations (Nelson, *et al*., 2010; Waithaka, *et al*., 2013). Other general circulation models are situated in between these two extremes. The main driving force of the global warming is the greenhouse gas emissions. Scenarios about the greenhouse gas emissions are provided by the special report on emission scenario where three models indicate two extremes: B1 scenario predicts lower emission while A1B and A2 show higher emissions in the future (IPCC, 2007; Waithaka, *et al*., 2013).

To the above scenarios, some of the models indicating how agriculture will then look like in the future include IMPACT (International Model for Policy Analysis of Agricultural Commodities and Trade) developed by the International Food Policy Research Institute; DSSAT (Decisions Support Services for Agrotechnology Transfer) (Jones, *et al*., 2003); and SPAM (Special Production Allocation Model); this last dealing with the area harvested, production and yield of crops in three different cropping systems (irrigated, low input and high input rainfed agriculture) (Waithaka, *et al*., 2013). To these scenarios, other scenarios about income generation and population growth are added. Three scenarios which are baseline, optimistic and pessimistic (Waithaka, *et al*., 2013) are used in association with other four scenarios which are "changed balance of power, a world in balance, a fragmented world and an overexploted world" (Öborn, *et al.,* 2009; Magnusson, *et al*., 2012) which include other important description of the influence that will be played by future power of States and intergovernmental organizations influence particularly in developing countries such as in Sub-Sahara (Magnusson, *et al*., 2012). Most of the predictions goes up to 2050, but others predict beyond this period.

In general, the global warming is predicted to increase than it is today in the future, making agriculture more vulnerable to climate change. According to different scenarios, the temperature increase is expected to vary between 1^{o}C to 4^{o}C or more in the coming decades (IPCC, 2007; Öborn, *et al.,* 2009; Nelson, *et al*., 2010; Magnusson, *et al*., 2012; Waithaka, *et al*., 2013) which will results in change of temperatures and precipitations distribution across the globe. These changes may expose some regions to severe drought, heavy rainfall, increase of pest and diseases incidence which in turn will make agricultural production and productivity more vulnerable (Öborn, *et al.,* 2009; Nelson, *et al*., 2010; IFAD, 2011; Magnusson, *et al*., 2012). The effect of climate change may become more severe to the growing world population which is projected to reach 9 billion in 2050 (Bogdanski, 2012) and especially to people in the developing world who are highly attached to rainfed agriculture for their livelihood. According to the income and population growth scenario, the population increases in developing countries but also the GDP growth rate is higher in these counties than in developed countries. For example, the countries of Eastern Africa will have a GDP growth rate higher than most of the European countries (Nelson, *et al*., 2010). Pessimists show that the world's population will increase which will then reduce the GDP while the optimists predict a reduction of the world's population enhancing then the increase of GDP (Nelson, *et al*., 2010; Waithaka, *et al*., 2013). Climate change will have a big influence on food and water security and availability due to high poverty rate and low adaptation ability in those countries, but also due to the increased population who directly or indirectly depends on agriculture. This will lead to pressure on natural resources such as land and the reduction of area, yield and production of agricultural products (Ringler, *et al*., 2010).

Asia and Africa are the mainly regions subjected to be more affected by climate change but the Sub-Saharan region is more predicted to experience the worse effect due to high dependence on rain-fed agriculture and due to low irrigation facilities (Ringler, *et al*., 2010;Waithaka, *et al*., 2013), but also due to low funds for climate adaptation and low support for agricultural development (Ringler, *et al*., 2010). Scenarios predict an increase of temperature in different regions of Africa. For example, in the Eastern Africa, higher temperature will reduce the agricultural production and will facilitate the breakdown of more pests and disease, but also the increase of rainfall may lead to crop failure which will increased food insecurity already affecting this region (International Food Policy Research Institute, 2009; Waithaka, *et al*., 2013). Shifting agriculture toward the Equator is predicted in Africa due to climate change. This can explain why a gain or loss of 5 to 25 % of production is expected in different countries of Africa (IPCC, 2007; Nelson, *et al*., 2010; Magnusson, *et al*., 2012;Waithaka, *et al*., 2013). Some area of Africa will experience severe yield losses while others will enjoy the potentiality of obtaining high yield, but in general the agricultural production in Africa will be exposed to a reduction of 10-20% (Thornton, *et al*., 2009). The region of Eastern Africa has an increasing population with a high population density in Africa. The prediction shows that the population of this region will even be more than double the current population in 2050. This may contribute to agricultural extension in reserved areas (Waithaka, *et al*., 2013) causing a huge impact on biodiversity and forests degradation. According to IPCC (2007), predictions for Africa under different scenario show that in 2020, about 250 million of people will be under water stress; a large area of about 5 to 8% will be transformed into arid or semi-arid in 2080 and the population in non landlocked countries will be affected by the sea level rise at the time close to the end of this century, consuming about 5 to 10 % of their GDP for adaption. The rate of vulnerability to climate change in African countries or in other regions of the globe will highly depend to temperatures and precipitations received and the capacity of adaption to future changes.

1.3. Climate change scenario on Rwanda in general and on agricultural sector specifically

Rwanda is a small landlocked country located in Eastern Africa with an area of 26.338km^2. The altitude in Rwanda varies between 900m and 4507m above sea level. The mean temperature is 20^{o}C and a mean rainfall of 1000mm per year (Ngoga, *et al.*, 2013). The neighboring countries are Uganda in the North, Burundi in the South, United Republic of Tanzania in the East and the Republic Democratic of Congo (DRC) in the West (Rwanda Environment Management Authority, 2011). The population of Rwanda was estimated to 10.5 million people in 2012 (National institute of Statistics of Rwanda, 2013), 12.3 million in 2014 (indexmundi, 2014) and this population is expected to double in 2050 according to scenarios (Ngoga, *et al.*, 2013). However, (REMA) Rwanda Environment Management Authority (2011), project the population of Rwanda to 33 million in 2050 due to the current high population density (419 persons/m^2) and the growth rate of 2.9%, which will cause more pressure on land, leading then to very small area per person in 2050 (Figure 3). More than 80% of the current populations depend directly or indirectly on Agriculture which is the main source of revenue for rural people and is mainly a subsistence farming dominated by small scale farmers (Ngoga, *et al.*, 2013). The population pressure has exposed Rwanda to land scarcity and shrinkage (Figure 3).The estimations given in figure 3 are based on the total land as the World Bank shows that the arable land per person in Rwanda was 0.1ha in 2012 (World Bank, 2015); and the FAO's arable land per person estimation in low income countries was 0.17ha in 2010 (FAO, 2011). These indicate that in 2050, arable land per capita in Rwanda will be a very serious issue faced by most of the Rwandans.

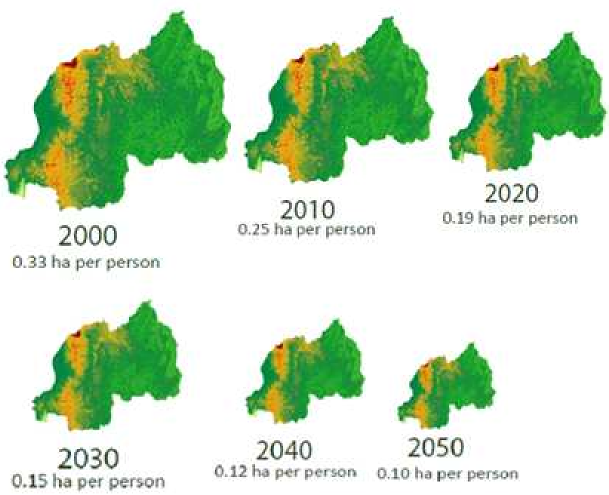

Figure 3: Area per person decrease due to population increase (estimates based on the total land including water bodies and reserved areas). Adapted to REMA (2011).

Farming systems in Rwanda are mainly mixed and monoculture farming (National Institute of Statistics of Rwanda, 2013). The mixed farming in Rwanda has been practiced for a long time up to now in the form of mixed intercropping. Intercropping is the cultivation of more than one crop in the same field (Food and Agriculture Organization of the United Nations, 1993; Hauggaard-Nielsen, *et al*, 2008). Due to land shortage, intercropping is common in Rwandan fields which helps to diversify food products at harvest. However, due to low productivity of intercropping, lack of knowledge important in crop selection for better intercropping among farmers and the willingness of the government to transform Rwanda into a middle income country by 2020, starting by agriculture on which most of Rwandan livelihoods depend upon, Rwandan government is enhancing the monoculture system (Ministry of Agriculture and Animal Resources, 2011). As the Rwandan economy is mainly based on agriculture, the government of Rwanda has invested in developing this sector. Different policies have been developed to rise the agricultural productivity among others crop intensification program, through land use consolidation program and regional crop specialization (Ministry of Agriculture and Animal resources, 2011). The purpose of these programs is to respond to the first goal of the millennium "Reduce extreme poverty and hunger" while contributing to food security and supplying the market (Ministry of Agriculture and Animal resources, 2011). The government plays a significant role in supporting these programs by helping farmers to get access to inputs such as chemical fertilizers and pesticides and improved seeds but also it strongly controls their implementation. The results of these policies show an improvement of crop yield of the major food crops at national level as it is visible in figure 4 (Ministry of Agriculture and Animal resources, 2011).

Agriculture in Rwanda is already facing the effect of climate change. The emissions from agriculture has increased remarkably since 1995 to 2010 from less than 1300 to 3000 gigagrams even if this emission is low compared to many other countries such as Sweden (Figure 5, A.); and this increase is expected to reach more than 4 thousand by 2050 as it is shown by figure 5, B.

The evergrowing population is causing pressure to land availability and now most of Rwandan farms have less than 0.5ha (Natinal Institute of Statistics of Rwanda, 2013). This has caused in turn pressure to protected areas where a reduction of 64% of protected forests is recorded during the period between 1960-2007 (Ngoga, *et al*., 2013). The overall natural vegetation was reduced to 59.4 % from 6 340 km^2 in 1960 to 2 575 km^2 in 2010 (Rwanda Environment Management Authority, 2011). The deforestation of these areas is mainly based on the extension of agricultural activities, new settlement and construction facilities, woods and charcoal production, etc. This pressure has a big role in facilitating the reduction of biodiversity hold by these natural and protected areas and contributing to climate change.

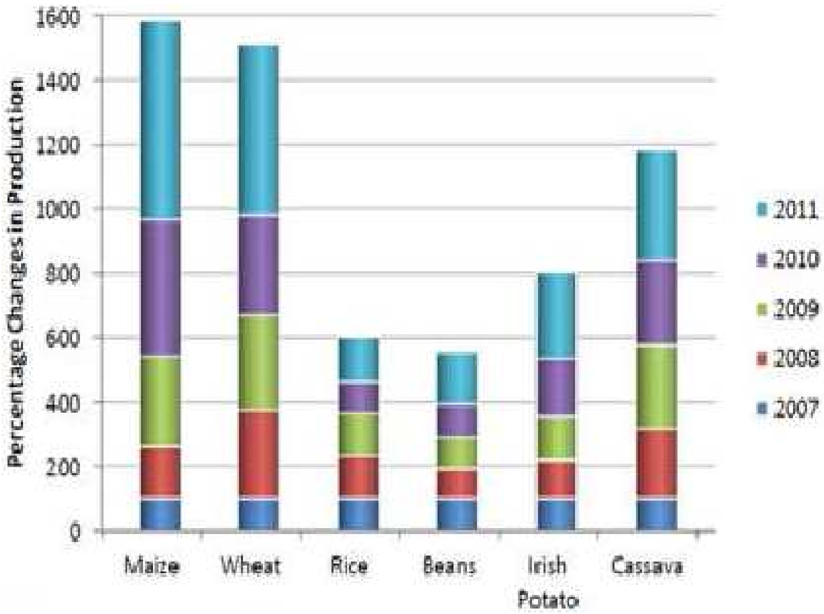

Figure 4: Percentage increase in production of major food crop yield under CIP, basing on 2007 production. Source: (Ministry of Agriculture and Animal resources, 2011).

In 2005, and 2007, severe floods in the Northern Province (figure 6) were attributed to the deforestation of Gishwati forest and its conversion into agricultural land (Rwanda Environment Management Authority, 2011). The Northern Province and some parts of the Western Province have a record of experiencing floods several times. Other floods are also recorded in Nyabugogo river plain and Bahimba valley. The most recorded are floods of 1997, 2006, 2007, 2008, and 2009 (Stockholm Environment Innstitute, 2009). The Southern Province mainly in the former Gikongoro and Butare, some regions of Northern province such as Musanze, and Burera Districts, and Western Province such as Rusizi, Rutsiro and Nyabihu District also have been exposed to severe soil erosion and landslides. These issues are mainly caused by higher amount of rainfall on unprotected soils (Rwanda Environment Management Authority, 2011; MIDIMAR, 2012). Another big issue is drought. Drought in Rwanda are due to rainfall reduction in some areas mainly of the Eastern and Southern Provinces which highly affect the agricultural production and caused severe famine and food shortage in the affected region (MIDIMAR, 2012). The well known is the drought in Bugesera District, former Umutara province and Mayaga region which occurs in 1998 and 2000 (ICPAC Kenya; SEI Oxford Office, 2009) but also during the period of 2002 and 2005 famine and malnutrition prevailed in many regions of Rwanda. In 2004, Rwanda faced a problem of water shortage leading to electricity shortage in the whole country but also in 2005 and 2009 Nyungwe National Park and Volcanoes National Park experienced fire hazards (MIDIMAR, 2012).

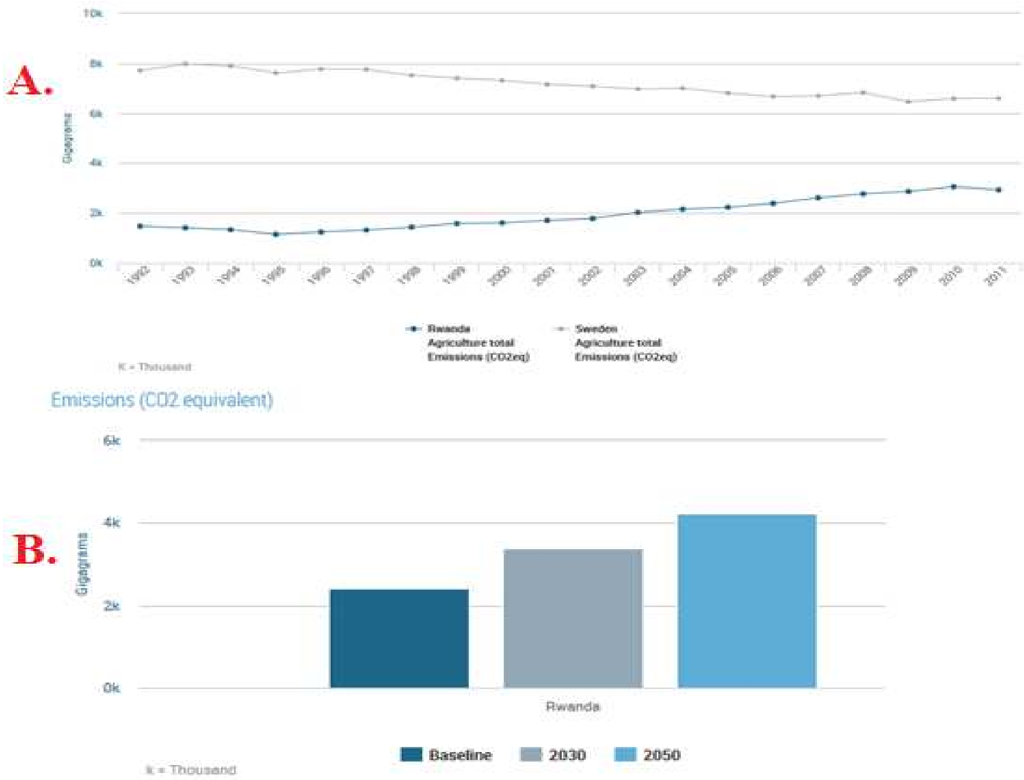

Figure 5: GHG emission from agriculture. A: Comparison between Rwanda and Sweden from 1992 to 2011; B: Future projection of Rwandan's agriculture contribution to emission (2030 and 2050). Source: (FAOSTAT, 2015).

Figure 6: Flood in Bigogwe Sector/ Nyabihu District. Source (REMA, 2011).

To these events, it is important to add strong winds and lightening which has caused drastic effect to Rwandan population. Table 1 summarizes different types of disasters which occur in Rwanda in 2013 together with their damages, all attributed to climate change.

Table 1: Damages caused by disasters in the year of 2013. Source (MIDIMAR, 2013)

Disaster Type	Died	In-jured	Demol-ished/ damaged Houses
Lanslides	35	18	379
Flood	15	-	266
Fire	1	3	7
mining	5	3	-
winds	28	47	3,282
lightning	28	53	-
Total	**112**	**124**	**3,934**

All these climate change events cause severe loss of the agricultural products and human lives in some cases but also have a big impact on socio-economic and environmental aspects of the country. Zimmerman, *et al*. (2012) estimated that during the period of 1974 to 2007, droughts and floods affected about four million and two million people respectively in Rwanda.

Recently, only in one week (since 11th February, 2015 to 16th February 2015), disasters such as lightning, heavy rains, strong winds and floods killed 15 people, 10 cows, 127 houses and large area of crops were damaged in different areas of Rwanda (MIDIMAR, 2015). By March 30, 2015, apart from human, livestock and houses destroyed, heavy rains and torrential rains flowing from Kalisimbi volcano washed away 30 ha of crops in Rubavu district (Sebuharara, 2015). Figure 7 shows how farms were severely affected after these torrential rains.

The situation of climate change may become worse in the future. Ngoga, *et al*. (2013), have used four general circulation models and the A1B scenario to predict the future temperatures and precipitation of Rwanda. These four models are: CSIRO Mark 3 predicting a drier future, has an increase in temperature from1^{o} to 1.5^{o}C; "CNRM-CM3 (a National Meteorological

Research Center–Climate Model 3 developed in France) and ECHAM 5 (fifth generation climate model developed at the Max Planck Institute for Meteorology in Hamburg)" both predicting no big change in precipitation in the future. They indicate an increase of temperature from 2^{o} to 2.5^{o} C. MIROC 3.2 predicting a wetter future, shows a higher increase of temperature from 3^{o}C and above.

Figure 7: Crops washed away in Rubavu District after the torrential rains flowing from Kalisimbi. Source (Sebuharara, 2015).

These scenarios will affect crops cultivation and production in different ways making loss or gain of productivity in some areas of Rwanda. It is for example sorghum which will gain about 25% under MIROC 3.2 scenario due to higher temperature and rainfall; the western and northern region will be able to produce more sorghum (Ngoga, *et al*., 2013). However, according to the income and population scenarios the population of Rwanda is also supposed to increase to about or more than 20 million which will then have a big impact on GDP per capita and the rate of malnutrition in children (Table 2).

1.4. Climate smart agriculture

To deal with the effects of climate change, a new approach: climate-smart agriculture has been developed. UCDavis (2013) defines climate-smart agriculture (CSA) as "an approach for responding to climate variability and change while providing the triple wins of food security, climate change adaptation and mitigation". According to FAO (2013) CSA is "an approach to developing the technical, policy and investment conditions to achieve sustainable agricultural development for food security under climate change". CSA has a purpose of achieving food security, adapting to climate change and variability and reducing or removing the greenhouse gas emission by developing and adopting efficient practices, policies, institutions, research, technology and finance (UCDavis, 2013; FAO, 2013).

Table 2: Rwandan population, GDP and malnutrition (number and percentage) under different scenarios. Adapted to (Ngoga, *et al.*, 2013; Waithaka, *et al.*, 2013)

		2050					
Indicators	2010	Pessimistic		Baseline		Optimistic	
Population (Thousand)	10,277	24,829		22,082		19,498	
GDP (per capita)	300	468		1,583		2,268	
		Min	Max	Min	Max	Min	Max
Malnourished children(thousands)	474	682	708	473	495	359	380
Share (%)	28.8	29	30.1	22.6	23.7	19.4	20.5

The implementation of this approach requires collaboration and participation of multiple stakeholders and disciplines, sciences, research and technology all enhanced by a political willingness and economical orientation change toward an effective management of resources, inputs and outputs of agriculture for a better future under a changing climate (FAO, 2013). While talking about CSA it is important to explain its three intertwined aspects: food security, climate change adaptation and mitigation.

1.4.1. Food security

Food security has been defined several times where in each definition, an important point have been improved or added. FAO (2003) has provided different agreed definitions of food security from different sources. In 1974, the definition of food security focused on the quantity and stability of food supplies in all times; later in 1984, it included the access of food to vulnerable people (supply fitting with demand). The improvement of the definition has continued where to the previous points, the quality of food: sufficient, safe and nutritious; food preferences and healthy life for all people and at all times have been added. According to FAO (2003), there is food security "when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life". Food security is determined by three main indicators which are food availability, food accessibility and stability, food accessibility and utilization (FAO, 2003).

Despite a great effort made in improving agricultural production, food security remains a challenging issue globally. An estimated 0.9 billion were undernourished in 2010, 1.4 billion were depending on less than 1.25 USD per day for their livelihood in 2005; on the other hand, 1.5 billion were overweighed in 2008 and the food produced for human consumption lost or wasted each year is estimated to 1.3 billion tonnes (Beddington, *et al*., 2012).

Addressing the issue of food security must be coupled with climate change as both aspects influence each other. Food systems produce greenhouse gases which lead to global warming but also the effect due to climate change are numerous. For example, 2 billion people lived in dryland areas in 2007; 1.5 billion depend on degraded or marginal areas and in 2011, while the cost of losses caused by climatic events was estimated to 11.4 billion (Beddington, *et al*., 2012).

1.4.2. Climate change adaptation

According to IPCC (2007), adaptation is defined as the "initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects". For human systems, adaptation has the purpose of moderating, avoiding or preventing negative impact of these changes or exploiting the advantages of opportunities created by these changes (FAO, 2013). Different types of adaptation exist. It is for example the preventive and reactive adaptation, public and private adaptation, autonomous and planned adaptation (IPCC, 2007; FAO, 2013).

Adaptation to climate change is not new to humans. They have developed the ability of responding to natural or human induced effects of climate change several times in the past (IFAD, 2011). It is for example migrations, extending agriculture to unexploited land, using synthetic fertilizers and pesticides, development of new crops and animal breeds adapted to change, etc. However some of these measures developed have enhanced the effect of climate change. Improved methods of adaptation are required in order to adjust to the changing climate.

1.4.3. Climate change mitigation

Mitigation means "technological change and substitution that reduces resource inputs and emissions per unit of output. Although several social, economic and technological policies would produce an emission reduction, with respect to climate change, mitigation means implementing policies to reduce GHG emissions and enhance sinks” (FAO, 2013).

1.4.4. Approaches and practices leading to climate-smart agriculture

There are several approaches and practices which contribute to CSA by enhancing climate change adaptation and/or mitigation while leading to food security at the same time. Many of them are listed in FAO (2013). It is for example ecosystem-based approaches; a conservation agriculture; organic agriculture; integrated livestock and crops systems; promoting of mulching and cover cropping; enhancing crop diversification and crop rotation; integrated weeds and pests management; water and irrigation management; fossil fuel replacement by energy crops; using improved and high quality seeds and planting materials adapted local conditions; efficient nutrients use and management; soil and land use management; promotion of legumes cultivation; agroforestry and so on. These approaches can be implemented individually or in combination with others for better ecosystem management. Some of these approaches are done at farm or household level while others requires the national or international intervention and investment for facilitating their adoption and implementation.

A conservation agriculture (CA), which is "a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. CA is based on enhancing natural biological processes above and below the ground" (FAO; FAO Subregional Office for Eastern Africa, 2009), has improved food production and resources conservation in many parts of the world. This approach is built on the following three major principles: Firstly, the minimum soil disturbance by reducing or suppressing the soil tillage; secondly, the keeping soil cover by preserving the residues, mulching or growing cover crops; and thirdly, enhancing crop diversification and crop rotations (FAO Subregional Office for Eastern Africa, 2009). In all case studies made in Kenya (Kaumbutho & Kienzle, 2007), Uganda (Nyende, *et al*, 2007) and Tanzania (Shetto & Owenya, 2007), the CA has led to increased soil fertility, reduction of labour and other inputs cost, increased production. But farmers indicated that this approach can led to increased use of herbicides as weeds prevalence becomes a challenging issue.

Another example is the diversified crop systems such as mixed cropping and intercropping. These systems engage the cultivation of more than one crop on the same land. Crop diversification has several advantages such as the reduction of weeds, pests and diseases occurrence, diversifying farm outputs thus decreasing impact crop failure, reducing farm inputs such as fertilizers and pesticides, efficient resources use such as land, water and nutrients, increasing soil fertility by reducing soil erosion and increasing biodiversity (Jensen, 1996; Whitmore & Schröder, 2007; Hauggaard-Nielsen, *et al*, 2008; Lin, 2011). Crop diversification is practiced in many parts of the world mainly in developing countries such as Sub-Sahara Africa where agriculture development is very low and subsistence farming is dominant. In developed countries, diversification fails mainly due to farm management as mechanization is the main driver of cultural practices, but also due to belief that crop diversification gives low yield than monoculture (Lin, 2011).

Agroforestry system is another diversified approach used worldwide. Agroforestry is a farming system which engages the cultivation of trees or shrubs in combination with crops, pastures or livestock and in which the interaction among components are socially, economically and environmentally beneficial at the same time (Alao & Shuaibu, 2013). The diversification in agroforestry system is maintained in space and/or in time (Lin, 2011). Agroforestry system has different forms such as agrisilviculture which includes crops and trees/shrubs, silvopastoral including trees with pasture/animals, agrosilvopastoral combining crops, trees and pasture/animals, and others (Ramachandra, 1993; Gliessman, 2007) all leading to two or more outputs. This system has several benefits among others barrier to extreme weather events such as storm and rainfall, improving soil health status, providing shade, keeping soil moisture by reducing evaporation, reducing wind and water erosion by increasing infiltration and acting as windbreak, diversifying farm output such as food and feed, firewood and timber, some trees are nitrogen fixing crops which lead to improved nutrient content and generally, trees are a good source of carbon sequestration and carbon storage (Altieri, 1995. pp, 253; Gliessman, 2007; Lin, 2011; Alao & Shuaibu, 2013). Hence agroforestry contribute to the triple wins of CSA.

Agroecology discipline is one of the interdisciplinary approaches used worldwide and which combines several of the above mentioned approaches and practices. Agroecology is defined as "the integrative study of the entire food system, encompassing ecological, economic and social dimensions" (Francis *et al*., 2003); or simply “the application of ecological concepts and principles to the design and management of sustainable food systems" (Gliessman, 2007). Agroecology orients into the development of agriculture through the conservation of resources and by providing the "modern ecological knowledge and methods" (Gliessman, 2007. pp, 18) required for it. These knowledge and methods lead to an agriculture which is environmentally, economically and socially sustainable. The principles and methods of ecology applied to agriculture are based on the assessment of the current and future sustainability of a farming system together with its inputs, practices and management. Agroecology is interrelated to CSA as both concepts have "agricultural sustainability" as a common target. FAO (1992) combines the definition of sustainable agriculture with a sustainable development. It is defined as follow: "Sustainable development is the management and conservation of the natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development (in the Agriculture, forestry and fisheries sectors) conserves land, water, plant and animal genetic resources, is environmentally no-degrading, technically appropriate, economically viable and socially acceptable". Sustainability in Agriculture does not mean only increasing yield. But this increase must be followed by a very low negative impact on the environment, the protection of and improving soil fertility, controlling soil erosion, good management of natural resources, reduced dependency on external inputs and the preservation of biodiversity, ensuring the equal accessibility to knowledge, practices and technology (Gliessman, 2007. pp. 17).

Some of the approaches listed above are used in different ways in Rwanda to encounter the effects of climate change. It is for example the integrated farming system, control of soil erosion by using radical and progressive terraces on sloppy areas, anti-erosive ditches and plants, zero grazing system, agroforestry, afforestation and reforestation and protection of river and lakes (Rwanda Environment Management Authority, 2011). These practices can lead to sustainable agriculture by providing enough food and lead to climate change adaptation and mitigation if well maintained and managed.

1.5. Justification of the study and research question, aim and objectives

Basing on the scenario for the future of Rwanda: increasing population at almost doubling the current population, increasing temperature varying from 1.5 to 2.5^{o} C more leading to much dryer or rainy seasons in Rwanda and the agriculture exposure to all these events, it sounds clear that all policies and projects aiming at improving agricultural production focus on the future predicted changes. The Western and Northern provinces which face huge floods and landslides are however the basket of agricultural production in Rwanda mainly producing potatoes, maize, beans and coffee (Zimmerman, *et al*., 2012). Musanze district (our case) located in the Northern Province experiences severe soil erosion and floods due to high rainfall and water from the volcanoes Park (Zimmerman, *et al*. 2012; Rwanda Environment Management Authority, 2011). This erosion causes severe agricultural loss and sometimes took away human life. As one of the important cities in Rwanda, Musanze district has a high population density and most of the population depends on agricultural activities (National Institute of Statistics of Rwanda, 2013). The agriculture in this district is intensive and does not leave soil cover, but the erosion control measures are not enough (Musanze District, 2013). Despite the high agricultural productivity level in this district and its classification as the third richest district in the country where 79.9% of its population is considered as non-poor, the malnutrition remains a challenging issue to the well being of its citizen (Musanze District, 2014) and 25% of the population still depend to surface water and unprotected spring

(National Institute of Statistics of Rwanda, 2012). With the projected scenario, the situation can be much worse in the future if no sustainable measures are taken. It is in this way this thesis will try to found a solution to the following research question: *How can the existing farming systems be improved in order to promote a climate smart agriculture capable to deal with the future climate change scenarios in Musanze District of Rwanda.* From this main question, three sub-questions will answered in this study. These are:

1. What are the main farming systems in Musanze District?
2. What are the causes and the consequences of climate change in Musanze District?
3. Which farming system can help to reach food security while both adapting and mitigating climate change?

The thesis aims at redesigning a farming system which can lead to good yield while having less damage to the environment. The objectives of this research will be (1) to identify the farming systems in Musanze District, (2) to identify the current effect of climate change in Musanze District and (3) to suggest an improvement of the existing farming practices which can deal with the predicted scenario

1.6. Limitations and obstacles

This research will be based on review of the predicted scenarios and the existing studies focusing on agriculture in Rwanda. However some data may be absent due to few studies and the country's ineffective way of recording and publishing information. This may have an impact on the efficacy of this research.

1.7. Structure of the thesis

This thesis is subdivided into five sections. The first section, introduction, includes the background of the thesis, explanations of approaches and concepts on which this thesis is based on, research question and its justification. The second section deals with materials and methods used in this thesis and shows how the data will be analyzed . Section three shows the results on the existing farming system, causes and consequences of climate change, and proposes a solution for improvement. Section four discusses the sustainability dimensions for the results towards a CSA. The last section conclude the thesis and suggests some recommendations.

2. Materials and methods

2.1. Description of Musanze District

Musanze district is one of the five Districts composing the Northern Province of Rwanda. It is made by 15 Sectors, 68 Cells and 432 Villages. It shares borders with Gakenke district in the South, Republic of Uganda and DRC in the North through the Volcanoes National Park, Gakenke district in the South, Nyabihu district in the West, Burera district in the East and Ruhondo lake in the South East (Musanze District, 2013). According to the National Institute of Statistics of Rwanda (2013), the population of this district was 416,000 with a population density of 694 inhabitants per square kilometer where 54.1% were female. Most of people are young where 84% are less than 40 years old. The district is the most mountainous in the country with an altitude varying between 1850 m to 4507 m above sea level (Musanze District, 2013). It has an area of 530.4 km^2 of which 60 km^2 are occupied by the Volcanoes National Park and 28 km^2 occupied by Ruhondo Lake (Zimmerman, *et al*. 2012). Due to higher altitudes, the District enjoys a tropical climate with an average temperature of 20^oC and higher precipitation ranging from 1400 t0 1800 mm annually (Musanze District, 2014). The daily life in Musanze depends basically on agricultural sector, engaging more than 91% of its population. The district produces mainly potatoes, maize, beans and wheat (Musanze District, 2013).

2.2. Methods

This study, is a review. It is basically based on secondary data (Davies, 2007) provided by other researches, reports and publications conducted on global climate change and scenarios of the future (prediction up to 2050), reports on Rwanda in general and on Musanze district specifically. This research will only focus on predicted scenarios on Rwanda but with emphasis on Musanze district as a key agricultural producer in Rwanda. Agriculture sector is an interdisciplinary sector influenced by or affecting other several sectors or factors.

Following are some of the most dominant issues affecting agriculture, but which in turn also are affected by this sector: climate change and variation, population growth, income generation. So, the scenarios have been developed by different institutions by taking into account all those issues. This study will focus on climate change and population growth as the most challenging issues in the future for Rwanda. Basing on the predicted increase of temperature of about 1 to 2.5^oC and the population almost doubling the current people of Rwanda, agriculture will be affected in different ways. This study will then propose a solution for the future. The solution is not only a single aspect. The study will enumerate others aspects to be considered when planning for a better future but will focus on agriculture domain.

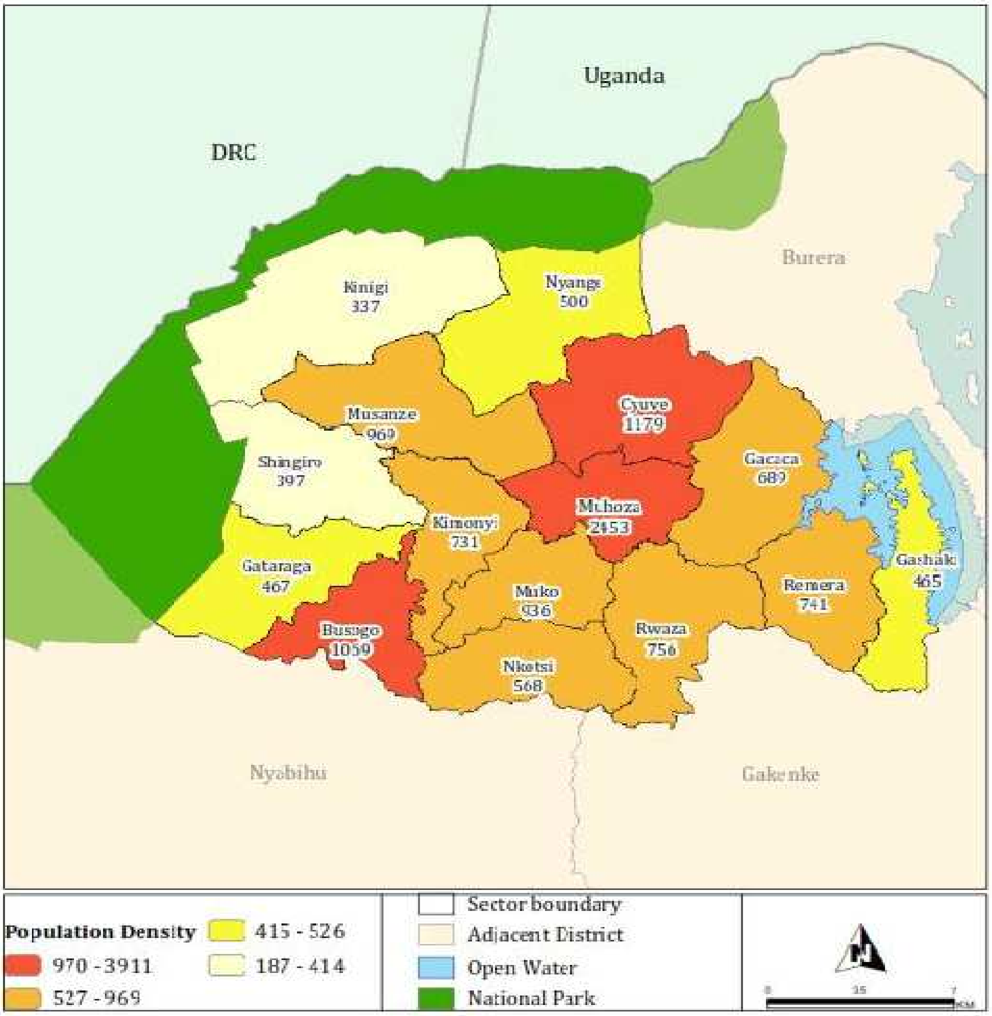

Figure 8: Musanze district with the population density in its sectors. Source (National Institute of Statistics of Rwanda, 2015).

2.2.1. Farming systems in Musanze District

To get the answer of the first sub-question which is "What are the farming systems in Musanze district?" it is first very important to remind the most limiting issue of this study: absence of recorded data in Rwanda. It is for this reason that this study referred to data available for the Northern province in which this district is located. These data are provided by the National Institute of Statistics of Rwanda (NISR) in its 2013 report on agriculture named "Seasonal agricultural survey report" (National Institute of Statistics of Rwanda, 2013). The survey was conducted on both small scale farmers and large scale farmers in all the Districts of the country. Apart from farming systems, this survey covered other aspects like characteristics of the farm in terms of area, yield and production, different farm activities and tools used on farm for all the three agricultural seasons [officially, season A (from September to January), B (from February to June) and C (from July to August) (Ministry of Agriculture and Animal resources, 2011) but these seasons vary from a region to another] of Rwanda.

2.2.2. Causes and consequences of climate change in Musanze District

To answer the second sub-question: "What are the causes and the consequences of climate change in Musanze district?” Two main reports were used. One was conducted by Luis Sanchez Zimmerman for MIDIMAR (Zimmerman, *et al.*, 2012). The report assessed the risks and vulnerability and the profile of livelihoods of the people affected by floods and landslides in Musanze, of Burera and Nyabihu districts. The second report used is named "Impacts of floods and landslides on socio-economic development profile. Case study: Musanze district" by MIDIMAR (MIDIMAR, 2012). Other information were provided by REMA and MIDIMAR which are in charge of environmental management and disaster management respectively.

2.2.3. Farming system which will deal with the future changes of climate

The answer to the third sub-question: "Which farming system can help to reach food security while both adapting and mitigating climate change?” is based on proposing a farming system which will lead to sustainability (including the following four dimensions of sustainability: governance, social, economic and environmental dimensions). The farming system to be proposed took into account the predicted climate change scenarios. This system is not new in the district, but it is an improvement of the existing farming systems and practices associated to them.

2.2.4. Data analysis

During the period of analysis, the following four indicators of sustainability were taken into account: good governance, environmental integrity, economic resilience and social well-being (Food and Agriculture Organization of the United Nations, 2012). These indicators are described in the assessment tool "SAFA: Sustainability Assessment of Food and Agriculture systems Guidelines" According to FAO (2012), SAFA is defined as "an assessment based on selected sustainability themes and sub-themes’ indicators of performance, which apply to a food company or production site that forms part of a supply chain rooted in primary production". SAFA is an international tool used to assess the sustainability of agriculture and food systems in a holistic way which combines all the four dimensions of sustainability listed above. The four dimensions are connected to their respective themes as it is shown in figure 9 below and to sub-themes. In this thesis, SAFA is used in the discussion section. The thesis then connected the four dimensions of sustainability to the triple wins of CSA which are food security, climate change adaptation and mitigation. In other words, this study analyzed the sustainability of the proposed solution.

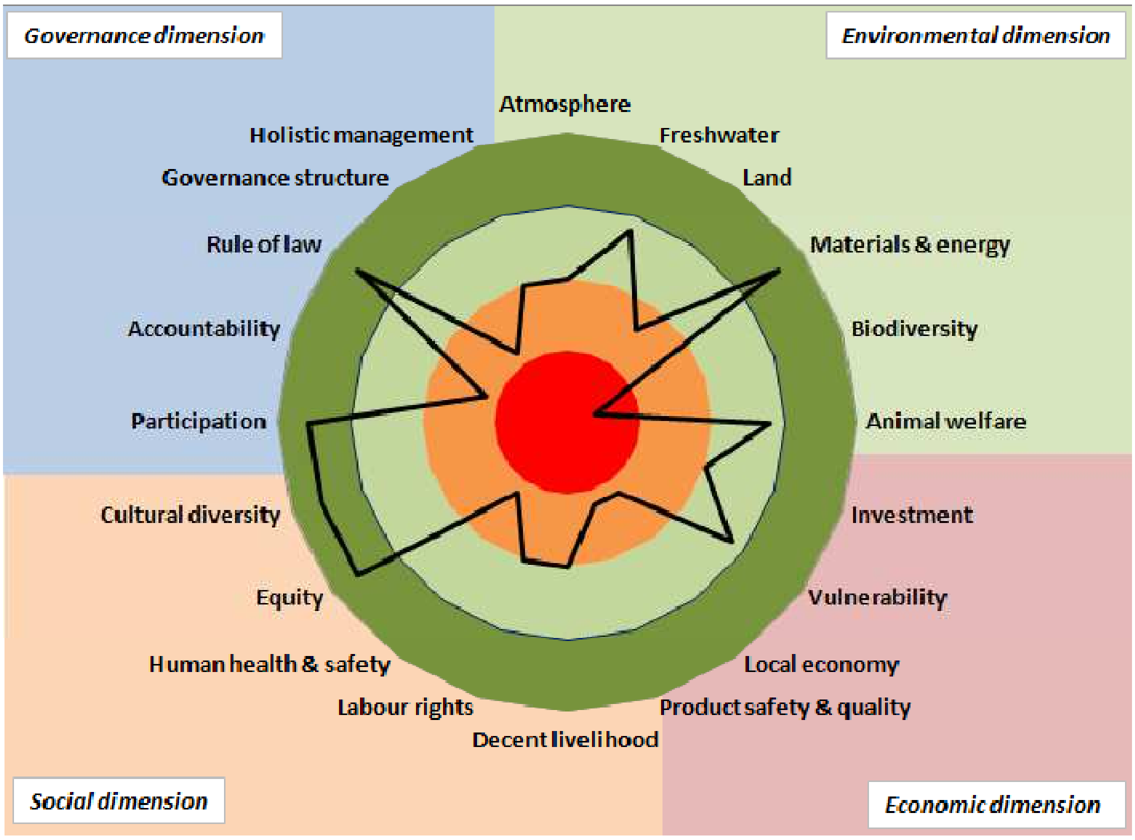

Figure 9: SAFA sustainability dimensions and their respective themes. The colors for the four cycles in the figure indicate how the theme is performed, and mean insufficient, moderate, good and best respectively for red, orange, clear green and dark green. Source (FAO, 2012).

3. Results

3.1. Existing farming system in Musanze District

Like others districts of Rwanda, life in Musanze district depend directly or indirectly on agriculture. Agriculture constitutes the main source of income in this District where about 91% of people are engaged in this sector (National Institute of Statistics of Rwanda, 2012). Volcanic soils are the most predominant in the district which explains the high crop productivity rate in comparison to other districts of the country (Maniriho & Bizoza, 2013). Apart from volcanic soils, there are by lateritic soils, soils rich in humus and clay (Zimmerman, *et al*., 2012). All farmers in Musanze are almost small scale farmers where 87% of households have less than 0.9ha of land; 50% has less than 0.3ha while the mean size of land per household is 0.45ha (Musanze District, 2013). This land size is very low for household as the mean size of household in Musanze is 4.8 (National Institute of Statistics of Rwanda, 2012). Farm activities are mainly carried out by female where 83% consider farming as their daily activity, while for men only 49% work on farm (independent farmer or wage at farm), 42% are wage non-farm and 9% are independent non-farm (National Institute of Statistics of Rwanda, 2012). The district produces mainly foods crops such as Irish potatoes, maize, beans, bananas, wheat, sorghum and different types of fruits and vegetables. It also produces some cash crops like pyrethrum (*Chrysanthemum cinerariaefolium)*, a cash crop mainly used in natural insecticide production; coffee and tea. Agricultural production of the main food crops in Musanze is higher than at national level as it is shown in figure 10 below. Households in Musanze also raise animals where 69% of household own some type of livestock such as cattle, sheep, pig, chicken, goats, etc. However the contribution of livestock to income generation is very small in this district which implicates that the main source of income for household is obtained from crop production (Musanze District, 2013).

The farming systems in Musanze district are also monoculture and mixed cropping as it is for the rest of other districts of Rwanda. The mixed farming which takes a large proportion of farmers in Musanze, is done in the form of mixed intercropping where different crop species are broadcasted on the same land. It remains subsistent and do not produce enough for farmers. For the monoculture, yield is increased and there is supply to other districts or even countries. Irish potatoes, maize and beans are among the selected best performing crops in this district together with pyrethrum.

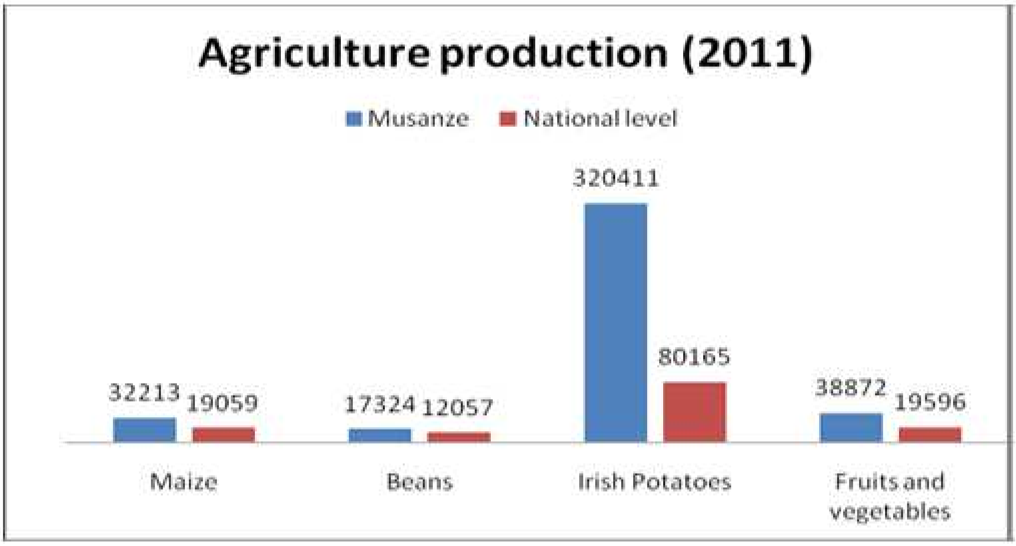

Figure 10: Average production (metric tonnes) of the main crops in Musanze district in comparison with the National level production (mean production of all the 30 districts of Rwanda) in season A and B of 2011. Source (Musanze District, 2013).

This district produces mainly many potatoes which are consumed nationally or are exported to the neighboring countries. Potatoes are grown in all the three seasons where in season A and B, potatoes are intercropped with maize, beans, or other crop while in season C potatoes are mainly grown alone.

The "seasonal agricultural survey report" conducted by NISR (2013) indicated how both small scale farmers (SSF) and large scale farmers (LSF) in the Northern province in which Musanze takes place, were involved in mixed cropping (MC) and in monoculture (M), in all the three agricultural seasons (see table 3). This survey did not include LSF in the season C.

Table 3: Percentage of farmers involved in both cropping systems in the Northern Province of Rwanda, where MC: mixed cropping; M: monoculture; SSF: small scale farmers; LSF: large scale farmers. Adapted to (National Institute of Statistics of Rwanda, 2013).

Season	A				B				C	
Cropping system	MC		M		MC		M		MC	M
Type of farmer	SSF	LSF	SSF	LSF	SSF	LSF	SSF	LSF	SSF	SSF
Share of farmer (%)	51.5	3.3	48.5	96.7	59.8	8.5	40.2	91.5	4	96

The survey also showed how the land was used by both SSF and LSF in this province. It indicated that 98.9% of land used to produce in monoculture were occupied by SSF in season

A and 99.4% in B while the land used in mixed farming, for both season (A and B), were almost 100% occupied by SSF.

In the Northern Province, the use of fertilizers showed that LSF farmers are able to get both organic and synthetic fertilizers while for SSF, the use of synthetic fertilizers is below 30%. However in season C, the percentage of SSF using synthetic fertilizers increased. Farmers also rely on the use of traditional seeds compared to improved ones even if for both seeds, the percentage is very low except in season C, where SSF depending on traditional seeds use rose significantly. The pesticides use was low for SSF except in season C while for LSF the use of pesticides is above 50%. The protection against erosion has increased and reached more than 80% in the Northern Province. Table 4 show the percentage of farmers (SSF and LSF) using inputs and control measures in all the three agricultural seasons in the Northern Province.

In Musanze district, the overall use of anti-erosive methods is estimated to 54% of the total land. The district is the fourth countrywide in using synthetic fertilizers where 46.5% of its farmers spend their cost of farm inputs on buying fertilizers and an estimated 29 kg per hectare are used.

Table 4: Percentage of farmers using fertilizers, seeds, pesticides and anti-erosive methods in all the three season of 2013 in the Northern Province, where SSF: small scale farmers; LSF: large scale farmers. Adapted to (National Institute of Statistics of Rwanda, 2013)

Indicators	**SEASON A**		**SEASON B**		**SEASON C**
Type of farmer	**SSF**	**LSF**	**SSF**	**LSF**	**SSF**
Fertilization:					
Organic	76.4	76.1	68.5	83.7	17.8
Synthetic fertilizer	29.5	73.1	21.4	67.4	80.7
Seeds					
Traditional	15.6	7.1	16.9	6.3	95.1
Improved	4.6	7.7	1.2	4.9	4.9
Pesticides	10.2	50.7	11.3	69.8	84.3
Anti-erosive methods	73.1	88.9	82.6	88.9	17.9

3.2. Causes and consequences of climate change in Musanze District

Musanze district owns a landscape which is composed by the volcanic plains (the central and north part) and the mountain range (the South-East). The volcanic plains have a mean altitude of 1860 m and cover the following sectors: Musanze, Muhoza, Muko, Kimonyi and Cyuve while the mountain range has a mean altitude varying between 1,900 m to 2,000 m. It covers over a third of the total surface of the district and includes Muhoza, Cyuve, Gacaca, Rwaza, Gashaki, Remera and Nkotsi sectors (Zimmerman, *et al*., 2012). A big part of the volcano national park is located in this district (MIDIMAR, 2012).

3.2.1. Causes

The district is exposed to temporal torrents originating in the volcanoes. They are caused by strong winds and heavy rains which make water to flow downhill from the volcanoes. Important torrents are Susa, Muhe, Rwebeya, Rungu, Cyuve, Kansoro and Mudakama (Zimmerman, *et al*., 2012).

The torrential rains and heavy rainfall are the main causes of floods and landslides occurring in this district which are facilitated by the topography of the district. However, the overexploitation of land due to unsustainable agriculture, overuse of the unprotected soils, deforestation and the low drainage system increases their effect but also; sometimes the normal channels of water are full of sediments which cause the water to overflow in different directions. Most of the sectors of this district on one hand or another experience floods, landslides and/or mudslides.

3.2.2. Consequences

The most exposed is Muko sector where water from several mountains and channels drains in this sector and cause severe floods. Other sectors affected are Kinigi, Nyange, Musanze, Shingiro, Gataraga and Busogo.

The recenty recorded floods and landslides occurred in April 2012. They were caused by torrential rains and heavy rainfall. The highly affected sectors were Shingiro, Busogo, Gataraga, Musanze, Kimonyi, Muhoza, Muko, Nyange and Kinigi. These floods and landslides caused severe damages among others 68 households were relocated, more than 85 house destroyed, one human death, 5 livestock died, thousands hectares of crops mainly of Irish potatoes, beans and maize washed away, forests and radical terraces slided, several thousand tons of soil eroded, fish pond destroyed, several infrastructures destroyed among other roads, streets, three bridges, three schools, one cell office and electricity cut off (MIDIMAR, 2012). Figure 11 shows some of these consequences.

Figure 11: Damages caused by the floods and landslides of 2012. a) transportation and circulation became difficult after floods; b) normal channel widened and followed by severe soil erosion; c) houses destroyed, crops destroyed and soil erosion. Source: MIDIMAR (2012).

3.2.3. Future changes

Based on the future scenario, Rwanda may become wetter or dryer depending to a type scenario used. Figure 12 shows changes in temperature depending upon four GCMs and A1B scenario (high emission scenario) and figure 13 shows their respective changes in rainfall while figure 14 shows an example of changes in yield of sorghum where in some areas of Rwanda, yield will be lost, gained or new area gained for cultivation (Ngoga *et al*., 2013). According to figure 13, it is predictable that precipitation in Musanze district will not be significantly changed, making this district to continue to experience high rainfall throughout the year.

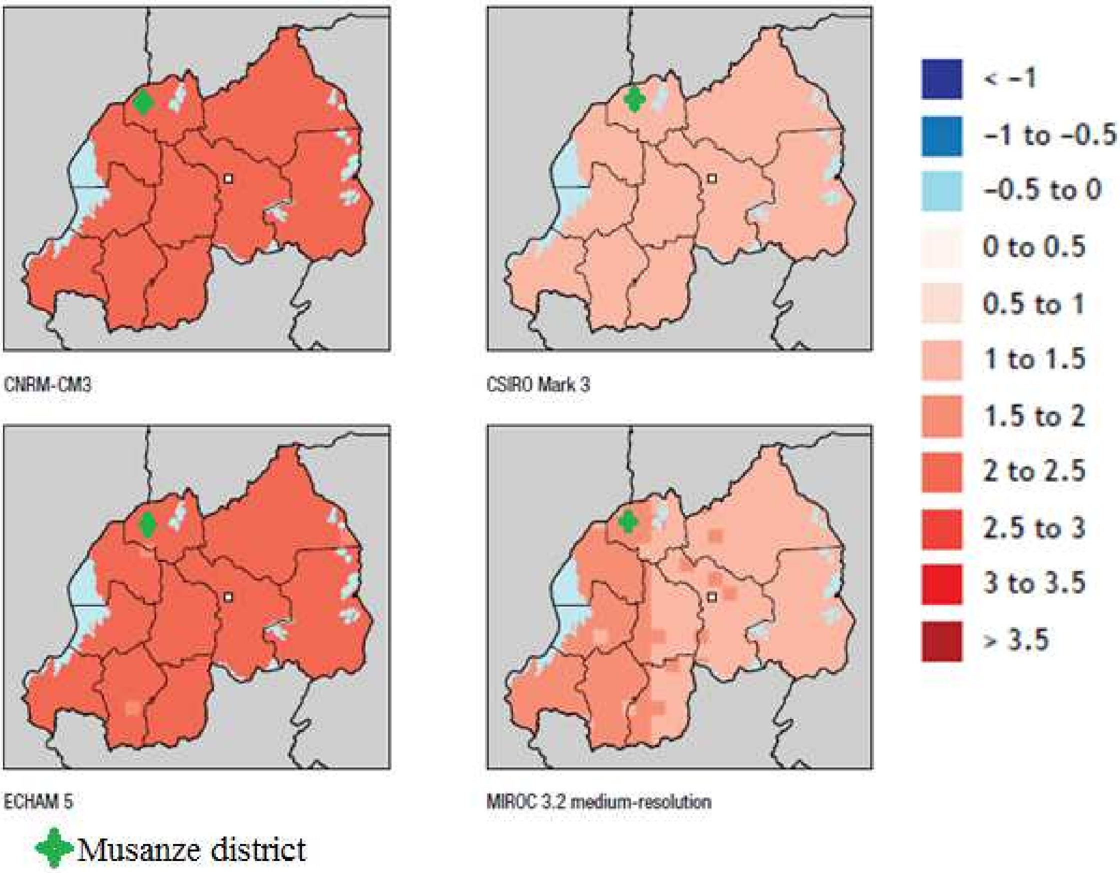

Figure 12: Changes in monthly mean maximum daily temperature (°C) in Rwanda for the warmest month 2000-2050, A1B scenario. Details are provided by Ngoga, *et al*.(2013).

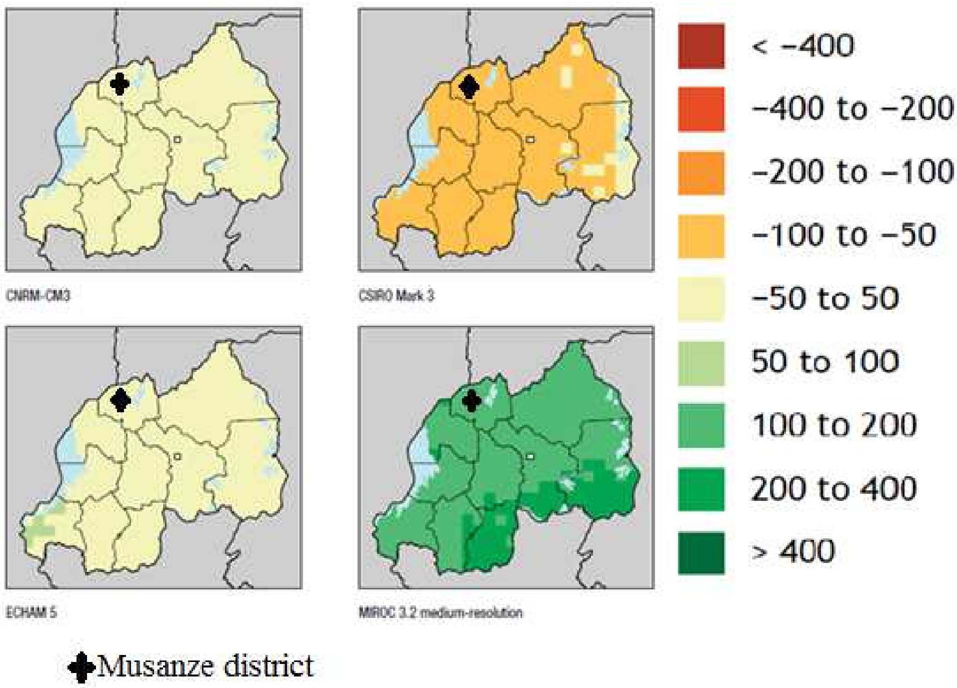

Figure 13: Changes in mean annual precipitation in Rwanda, 2000-2050, A1B scenario. Details are provided by Ngoga, *et al*. (2013).

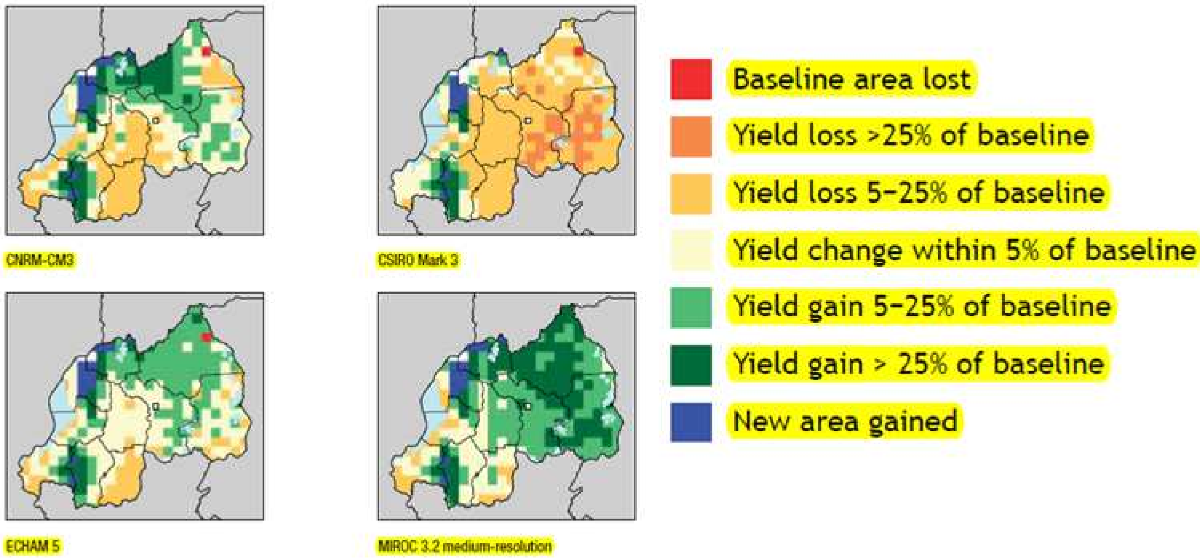

Figure 14: Yield variation of sorghum under different scenario. Details are provided by Ngoga, *et al*. (2013).

3.3. Mixed farming as a solution for improvement

In a country like Rwanda, where the changes in current (Figure 12) and the projected (figure 13) emission from agriculture is low (less than 5.000 Gigagrams in 2050), climate change adaptation and food security aspects of CSA are very important to focus on than enhancing climate change mitigation. Due to this issue, mixed farming is suggested as a way towards adaptation and food security primarily and thereafter participating to mitigation in the other way.

3.3.1. What is mixed farming?

Mixed farming is defined as farming systems where crops and livestock "form integrated components of a single system" (FAO.org). In this system, crop cultivation becomes the main component of the system while the livestock rearing is the second. Even if mixed farming requires enough knowledge for better management and labor subdivision into different activities required on farm (FAO, 2001), it has many benefits among others reducing the risk of failure and facilitating farm intensification, efficient use of resources such as land, nutrients and labor, generating a source of money to buy inputs (mainly from the sale of livestock), reducing dependency to external inputs and enhancing biodiversity, preserving the ecosystem services and enhancing the processes, preserving soil fertility and enhancing the nutrients recycling where for example crop residues are used to feed animals which in return produce manure to fertilize the soil, to reduce soil erosion and promoting crop rotation, and leading to the diversification of farm outputs (De Haan, *et al*., 1997).

There are many types of systems in the mixed farming. FAO (2001) showed that they are classified depending upon mainly on the following four major aspects: "land size, type of crops and animals, geographical distribution, market orientation" on which three major forms are identified:

(1) *On-farm versus between-farm mixing*. On-farm mixing means mixing on the same farm and this happens when a farmer is able to recycle all the resources owned on his own farm. Between-farms mean resources exchange from farms to other farms. In this system, farmers do not have the ability to recycle the resources they have on their farm and prefer to exchange them with other farmers. For example a crop cultivator offers crop residues to a livestock keeper in exchange with manure (FAO, 2001).

(2) *Mixing within crops and/or livestock*. This mode means that there is a mixture of different crops or different animals over time and it mainly refers to on-farm mixing. Mixing within crops engages the practice of crop rotation over or within years. The mixture varies from mixing different types of crop species or mixing different varieties of the same crop. Mixing within livestock has different benefits such as providing nutrients to one type of livestock, better utilization of biomass or to reduce the effect of disease incidence (FAO, 2001).

(3) *Diversified versus integrated systems*. Diversified systems means that components (crops and livestock) "coexist independently from each other" and has the only aim of minimizing risks not to recycle the resources; while integrated systems engages the inter-dependency among components (crops and livestock for example) and enhances the recycling and maximum use of resources (FAO, 2001).

Some of the forms of mixed farming system listed above exist in Rwanda in general. On-farm mixing is more practiced compared to between-farm mixing. Mixing within crops and/or livestock is also predominating but for crops, the mixture is mainly based on different crop species than varieties or cultivars. Integrated farming system is also done mostly due to lack of access to external inputs mainly chemical fertilizers.

3.3.2. Complex mixed cropping (CMC) suggested as a solution

In an area like Musanze district, with high population density and population depending highly on agriculture, but facing a problem of land scarcity and vulnerability to floods and landslides which lead to severe soil erosion and environmental damages, a more complex form of mixed farming system becomes very important to keep producing but also enhance adaptation to changes. This study focuses mainly on the cropping system unit due to the fact that farmers' livelihood in this district depends mainly on crop production and livestock has low influence to their life. But the study recognizes the role of livestock on farm and show the interaction of the crops components of the farm with the livestock component.

Basing on Spedding (1975), Altieri (1995) shows different factors required in choosing a farming system. These factors are based on resources availability, challenges and conditions faced by each region (Altieri, 1995. pp, 90). For these reasons, this study proposes then a complex mixed cropping (CMC), composed by *a crop mixture within farm/fields such as (1)* ***strip cropping*** (insider of figure 15) *or (2)* ***row intercropping*** *all together with* ***perennial trees or shrubs and/or anti-erosive crops*** *at the border of the farm/field* as it is shown by figure 15.

Strip cropping is done by growing different crops in the same field and in the same growing season. It requires making strips of 3m to 9m large of varied crops like maize, beans, potatoes and vegetables. It has several benefits among others enhancing crop rotation, diversifying products, improving soil fertility, reduced competition among intercrops, easy to manage and produce residues which are used as soil cover (FAO). *The row intercropping* is a form of intercropping where the main crop is grown in rows and the other crops (such as cover crops) are broadcasted in between or both intercrops (the main and other crop) are grown on rows (FAO). Maize can be grown as a main crop while sweet potatoes, groundnut, beans, pumpkins, etc as second crops which are broadcasted in between rows of maize, or both maize and intercrop are sown as main crops in rows. This system has the same benefits with intercropping but also it can provoke a competition among species for resources.

Both forms (strip intercropping or row intercropping) are proposed for the insider of the farm. For the border, this study proposes planting perennial trees and/or shrubs with anti-erosive crops between them or using dense shrubs only. The main purpose is that these species have a good ability of controlling erosion but also they produce feeds for animals or farmers can make compost or use them as green manure and they are a very good source of carbon sequestration (FAO, 1996); but also, there strongly recommended to regions with high population densities, people living marginal areas (sloppy and degraded soils) and to SSF (Altieri, 1995. pp, 260).

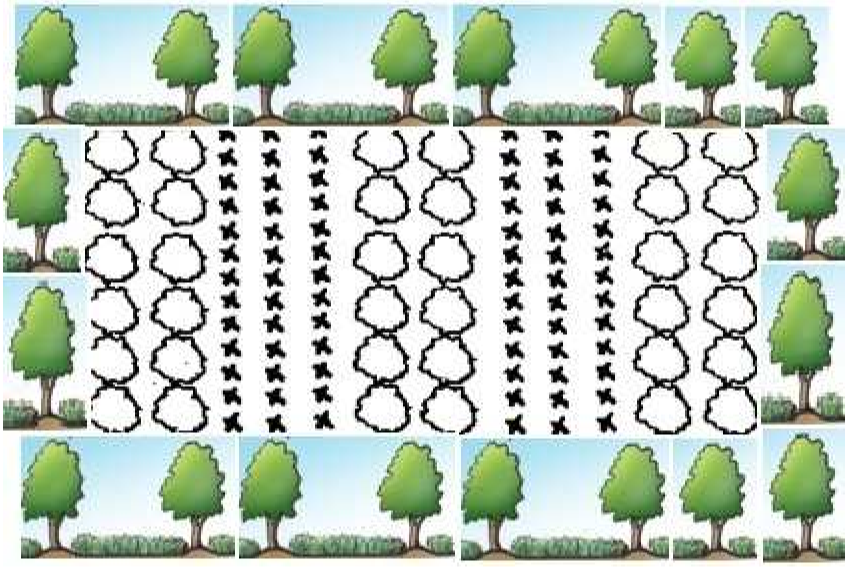

Figure 15: Proposed cropping system: A complex mixed cropping. Source: contour trees/shrubs and/ anti erosive crop: http://nac.unl.edu/buffers/guidelines/4_opportunities/5.html; inside crop mixture: http://www.fao.org/wairdocs/ilri/x5545e/x5545e04.htm.

What is needed is the knowledge and skills required for the identification and selection of crop species and trees/shrubs which can be mixed together and have very low competition for resources use and promote complementarities between species (Altieri *et al*., 1978); but also for choosing better plant densities, spacing, and practices required for the management of the mixture (Seran & Briantha, 2010). Crops that perform better in the district are already known. For the trees/shrubs, agronomists can help to identify them. Farmers can easily adopt trees/shrubs which are nitrogen fixing, controlling erosion, edible like fruit trees or producing feed. Following are some of the examples of agroforestry trees commonly used in Rwanda: *Calliandra calothyrus, Cedrela serrata, Grevillea robusta, Leucaena diversifolia, Mimosa scabrella, Moringa oleifera and Alnus acuminata* (Rwanda Environment Management Authority, 2010). The access to these species and their adoption cannot be a big issue once well explained as the government of Rwanda has introduced nurseries in many cells of country where farmers can get agroforestry trees for free (Kuria *et al*., 2012) and services extensionists/agronomists are available for information provision. For the anti-erosive plants farmers have the habit of sharing planting materials many times for free. So training farmers about how to prevent erosion as the main challenging issue they face using CMC and showing them the extra benefits they can gain from it such as keeping the yield increased, maintaining soil fertility and soil cover, feed for their livestock, diversifying food products and money from selling the trees can motivate them and facilitate the adoption.

3.3.3. Reasons of proposing CMC

This complexity is based on the will of the government to improve agriculture production. The government of Rwanda helps and encourages farmers to get access to synthetic fertilizers and improved seeds in order to increase productivity. It also encourages the monoculture of selected crops in each district under regional crop program (a program which promotes the cultivation a single best performing crop in a region) which is enhanced by other programs like crop intensification and land use consolidation in order to increase production per unit area, food security and supply to market. Due to crop regionalization, farmers have been claiming that they are forced to grow only a single crop on their farms which sometimes do not cope with their choice and to which expenses are more than outcome. It is for example pyrethrum (Huggins, 2012; Habimana, 2013) and maize (Huggins, 2012) where farmers have indicated that the other crops that were grown with the selected crop were uprooted which caused conflicts between them and the local authority. Another important aspect is that the government of Rwanda has inaugurated a program called "One cow per family" also called "Girinka Munyarwanda" (Ministry of Agriculture and Animal resources, 2011) in the mother tongue in all the district of Rwanda. This program has the purpose of helping mainly poor families to get access to manure and improve their nutrition. As in Rwanda an approach of "Zero grazing" (Rwanda Environment Management Authority, 2011) is applied, it become challenging to SSF to find feed for their livestock and this could become more challenging in the future where land is expected to be more scarce. The proposed solution is also based on the cultural aspect of farmers in Musanze district on agricultural rotation. People in this district are used to both sequential and relay cropping. For example, farmers like to grow potatoes alone. After it is harvested, they grow beans, maize, sorghum, or another crop. But, sometimes it may happen that tubers from the harvested crop germinate, in this case, they keep them on the farm and grow with the planted crops, which help them to diversify farm output.

The use of the synthetic fertilizers as a way to improve soil fertility is challenged by farmer's ability to buy them (Huggins, 2012; Musanze District, 2013) but also due to the problem of heavy rains which cause severe soil erosion followed by washing away the crops together with the fertilizers applied. Also by taking a look on the future scenarios, the district will probably not face drought but probably the intensity of rains will increase and increase also the soil erosion and degradation.

These issues show that relying on chemical fertilizers as a way to improve soil fertility will not work in the coming years and the crop production will be highly affected. Farming systems and practices that lead to increasing yield and which are environmentally sounds are to be encouraged for the current production but also for ensuring a future production.

3.3.4. Benefits from this system in Musanze district and in other parts of Rwanda

Mixing crops within the farm/field will help to reduce the risk of failure and enhance crop rotation which help to improve soil fertility and reduces the incidence of pests and diseases (Seran & Briantha, 2010; Lin, 2011). The use of use of perennial trees or shrubs (mainly nitrogen fixing crops) will enhance water retention and infiltration, improve soil fertility and soil organic matter, provide food and source of income to humans, feed to livestock and litter as soil cover, and reduce soil erosion (Lin, 2011). Also enhancing the use of anti-erosive plants will reduce the soil erosion and provide feed to animals. Anti-erosive crops can also be replaced by hedge rows of shrubs which have little competition with crops inside the farm such as Calliandra and Leuceana species already used in many regions of Rwanda.

Once adopted, farmers located in the areas reserved for pyrethrum production will be more beneficial as it will help them to diversify farm produce while keeping producing pyrethrum but also it will solve the conflicts based on its cultivation as pure stand only which farmers have claimed to be beneficial to the government only and to other inputs providers. Pyrethrum can be intercropped with other crops. A typical example is shown by farmers in Kenya where its intercropping with maize reduces pests and diseases but also do not affect the quality of pyrethrum flowers. It also helps to use the land efficiently as maize is grown in between rows of pyrethrum (FAO, 2001).

This CMC will help to control the intensity of soil erosion as it is the main challenging issue faced and solve the problem of crop regionalization which engage the cultivation of a single crop per season and to which farmers have been resisting to its implementation. The target of the crop regionalization was to increase production, so, this will be achieved in another form (CMC) because crops like maize and beans can grow together and the yield of both components is not reduced (Seran and Briantha, 2010). Another important benefit, is the production of fodder for livestock by trees/shrubs or the anti-erosive plants, but also the crop residues from crop mixture inside the field can be used as feed.

4. Discussion

In this section, SAFA is used to discuss the sustainability of the proposed solution in connection to the three pillars of CSA (food security, climate change adaptation, and mitigation). SAFA has four dimension of sustainability (good governance, environmental integrity, social well-being and economic resilience) which are discussed below. The four dimensions are associated to their respective themes and sub-themes shown in figure 9. This work did not go in depth to discuss the themes and sub-themes or to rate the themes of each dimension but it discussed the four dimensions in general due to lack of data necessary for the assessment. For this reason some themes are selected and discussed based on the existing farming systems and then show how they could be improved basing on the proposed solution.

4.1. Sustainability of the proposed solution

4.1.1. Good governance

The government of Rwanda plays an important role in the development of agriculture. Apart from establishing policies, rules and regulation that farmers must follow, it also participate actively in searching for investors and donors in order to develop agricultural sector. The government is the main initiator of almost all the programs and projects in agricultural sector and which has played a significant improvement of the agricultural production and the living of the population. It is for example, the crop intensification program (CIP) and its related sub-programs such as regional crop specialization, land use consolidation, extension services and inputs provision (Ministry of Agriculture and Animal resources, 2011). It also help in the control of erosion and fighting against the deforestation by enhancing reforestation and afforestation and the protection of natural reserved areas such as parks and lakes and to show how the areas closed to these protected areas are used. Farmers have little or even no influence in participating in decision making and they are simply implementers of the decided actions concerning their farms. This has been observed in many programs where their implementations were considered as an obligation to farmers. A typical example is the CIP, land use consolidation program and regional crop specialization in Musanze district (conflicts raised mainly by farmers whose area is selected for pyrethrum growing but also for other crops) and in other districts like Kirehe (Eastern province) where maize is the first selected crop, Muhanga (Southern province) where among the selected crops, flowers and fruits were the focus. In all this areas (data available) but also in other regions (not studied) farmers have had conflicts with the local authority as growing a single crop on their farm is seen as a way to expose them to hunger but also to work for governmental profits only (Huggins, 2012;

Ansoms, *et al*., 2010). Another reason is that farmers have the culture of diversifying crops on their plot of land as for many of them; the daily food is obtained from the field.

Further critical analysis of the governmental intervention in the agricultural sector in Rwanda are provided by different papers by Huggins (2012), Ansoms and his collaborators among other Ansoms, *et al*. (2010), Ansoms and Rostagno (2012). They all show the great effort of the government to develop the Rwandan agricultural sector through different policies and programs but also their associated challenges created by their implementation: farmers claim to be forced to implement those policies and some are resisting to their execution. Sterman (2002) explained well why policies are resisted. He mentioned: "As the world changes ever faster, thoughtful leaders increasingly recognize that we are not only failing to solve the persistent problems we face, but are in fact causing them. All too often, well-intentioned efforts to solve pressing problems create unanticipated ‘‘side effects’’. Our decisions provoke reactions we did not foresee. Today’s solutions become tomorrow’s problems". These side effects created by seeking solutions are the main causes of policy resistance by implementers.

The way used to reach these solutions (forcing) in Rwanda is also a treat to farmers. The official document of land use consolidation program for example makes clear that farmers are 'democratic' and that a 'voluntarily participation' is required for its implementation (USAID, 2007) but at the time of its execution, local authority make it 'a must'. This makes farmers to see their leaders as their enemies instead of their facilitators. A clear "instrumental rationality" approach of facilitation (Groot & Maarleveld, 2000) is used in Rwanda in order to reach different goals set at national level. This type of facilitation simply "values actions in terms of their ability to achieve pre-set goals by manipulating others (things, people) as objects. One does something because it is a way of achieving one’s goals" (Groot & Maarleveld, 2000). This definition fits with farmers' claim that the profits are enjoyed by other stakeholders while the goal of their introduction were first to improve farmers' livelihood.

The reason of this type of facilitation can be seen on one hand in the fact that farmers have a very little knowledge of farm improvement but also their high rate of illiteracy among Rwandans which makes the government to be more involved in decision making and implementation of different programs without concerns of farmers. On the other hand, the reason can be the "Best performing approach -*Imihigo*- in mother tongue" used in the all sectors including agriculture in the country for pre-set goals and targets achievement.

Imihigo approach was introduced in Rwanda during the Kingdom regime before the colonial time. Imihigo is "a cultural practice in the ancient tradition of Rwanda where an individual would set himself/herself targets to be achieved within a specific period of time and to do so by following some principles and having determination to overcome the possible challenges" (Rwanda Governance Board, 2012). After a set of time period, presentations were led by the king where the best performers were awarded. This approach was reintroduced again in 2006 as a tool to accelerate and reach local and national plans at a very high percentage. Imihigo (pre-set goals) are signed yearly by high authorities from the district level and above with the president of the republic and they are also evaluated every year in a meeting with the president where winners are encouraged and least performers have to give tangible reasons of their failure. So local leaders in their struggle to perform at high percentage their pre-set goals 'force' to implement different programs at any cost without taking care of farmers options or worries.

With the CMC, a clear change in reaching pre-set goals is highly needed mainly in the agricultural sector which has a big influence on the lives of almost all Rwandans. Any decision taken in this sector has a significant impact (negative or positive) which may improve or worse the socio-economic aspect of the Rwandans but also on the environment.

The implementation of CMC requires first that the government enhances the participation and intervention of all stakeholders starting by the first beneficiaries and implementers (farmers) and other public or private sectors. Groot & Maarleveld (2000) define the participatory intervention as a way of "involving all relevant actors in the change process". This then promotes better learning where all the stakeholders with their different views, goals and understanding participate in solving problems/conflicts and get out with a common understanding of the solution which is effective and sustainable (Groot & Maarleveld, 2000).

Different opinions raised by farmers against policies aiming at improving agricultural sector in Rwanda are a good base for facilitating changes and transitions (Driver & Kravatzky, 2000) towards a better future. But also, learning from the previous identified mistakes and 'accepting criticism' (Haley & James, 2002) is an important way toward a sustainable improvement with low negative effects.

It requires a shift from an instrumental rationality to a strategic rationality where people are viewed as 'actors' instead of manipulating them as objects for the achievement of the pre-set goals, or to increase the degree of participation to a communicative rationality where "action is taken through agreement and shared understanding. One does something because of a feeling of commitment and interdependency with others" (Groot & Maarleveld, 2000). Strategic rationality is chosen as a next step because it promotes at a certain level the collaboration of different stakeholders for enhancing a better efficiency and effectiveness in any type of implementation (Helmfrid, *et al.*, 2008).

Once the complex mixed cropping approved by the government, together with the adoption of strategic rationality, it will slow down the traditional 'top-down' flow of information model (Helmfrid, *et al.*, 2008), in which information comes from experts to farmers and considers people as ignorant; to a level where farmers' needs and preferences are appreciated and considered important. It will also change the 'supply-push' to a 'demand-pull' approach of inputs flow (Huggins, 2012) mainly chemical fertilizers as farmers will buy inputs because they need them.

What is mostly needed is to ensure and sustain peace and security in the African countries if a sustainable agricultural development is to be undertaken as it is recommended by Egziabher & Edwards (2011). Rwanda is located in the East Africa and in the region of great lakes, regions which have and continue to face wars and conflicts. It has fell into ethnic conflicts which has led to genocide against Tutsi in 1994. After the genocide, a rebellion, FDLR (Force Democratic pour la Liberation du Rwanda in French), was created mainly by extremists Hutu who had committed the genocide and they installed in the Eastern DRC. These rebels have been and continue to plan their attack on Rwanda. They have been causing insecurity in the country mainly in the former Ruhengeri province (Focusing on the current Musanze district) and the former Gisenyi province both located in the North-West region of Rwanda. It is in this region where the Volcano National Park is located on the side of Rwanda and is extended to DRC changing the name and becoming Virunga National Park. As it is a natural forest, they hide themselves in it and it constitutes their main attacking point. There are many consequences rising from internal or external war or conflicts as indicated by FAO (2000) while talking about relationship between conflicts, agriculture and food security. It showed that apart from losses of human lives, agriculture sector is affected mainly by migration which makes land uncultivated; livestock and crops abandonment and destruction by fighters; transport, market, and inputs access disturbance. For the agriculture recovery, this report recommended not only to focus on policies leading to short term revenues but to enhance long-term development which exigent participation in decision making towards improvement.

4.1.2. Environmental integrity

Rwanda has very low agriculture GHG emissions (figure 5). This is due to the fact that agriculture sector is not also well developed. Inputs like chemical fertilizers and pesticides, machinery like tractors which require the use of fossil fuel and irrigation system are very limited. The country has banned the use of plastic bags as they are not biodegradable materials, burning crop residues and burning forests. These have in turn contributed to decreasing greenhouse gas emission and air pollution.

However, due to the hilly and sloppy aspect of Rwandan topography which make the country to be called 'country of thousand hills' (Rwanda Environment Management Authority, 2011), overexploitation of land and deforestation mainly due to agriculture done on fragile and unprotected soils have exposed land to severe degradation (Green World Consult, 2014). Regions like Musanze district and others located in mountainous areas are prone to floods and landslides due to heavy rains and are exposed to severe soil erosion followed by washing away most of the crops grown and inputs applied mainly fertilizers. The soil, fertilizers and other type of wastes end in rivers which collect them into Mukungwa river which to its turn drives them to Nyabarongo river an affluent of Nile River. This has an a negative impact on marine fauna and flora and may lead to eutrophication and acidification but also to the lives of Rwandan as it is indicated by Green World Consult (2014) who are still depending to unimproved source of water (such as rivers and lakes) for domestic use including drinking water. For example, an estimated 26% of households use unimproved drinking water in Musanze district (National Institute of Statistics of Rwanda, 2012). This is a severe treat to sanitation as a significant percentage of people are exposed to diseases such as diarrhea only due to unpurified water. As the future predicts to become dry, keep at almost in the way it is today or become wet (Waithaka, *et al*., 2013; figure 13), pro-actions are needed to prevent or reduce damages which may follow these changes. Probably, Musanze district will not experience droughts as the dryer scenario (CSIRO Mark 3), predicts a change between -50 and +50 mm, a change which may not probably eliminate flood incidences. This explains why farmers have to adopt a farming system which is more diverse, which helps to control erosion and help to improve soil properties. But also this system is important for the rest of the country such as the Eastern and part of the Southern where droughts are currently and probably future big challenge as it helps to keep soil moisture and reduces the risk of crop failure. The promotion of monocultures is a treat to the biodiversity as some crops are no longer grown and it takes away some soil fauna, but also soil erosion is severe on soil where monoculture is practiced compared to mixed cropping system. Monoculture is also a treat to natural habitat as uniformity of crops destroys the natural niche of some species like pollinators and beneficial insects and disturb the natural processes. Processes like crop rotation and diversification, and the use of legumes as nitrogen fixing crops which enhance the soil fertility and reduce the outbreak of pests and diseases are of limited interest in monoculture. These processes are replaced by the use of chemical inputs such as pesticides and fertilizers (Altieri, 2011).

The country has adopted the 'zero-grazing' approach in order to reduce intensity of animals on fragile soils which caused land displacement and to increase manure handling and collection. This may have an impact on animal welfare such as freedom of locomotion and feed selection even if studies are not conducted yet. A study conducted in United Kingdom by Haskell, *et al* (2006) shows that cows in zero grazing are more exposed to knee swellings and health issues of leg and foot are prevailing. Another issue is that land is getting so scarce and this is a treat to animal feeding. As the system of 'cut and carry' is used, it becomes challenging to farmers to get all the feeds required on their plots of land.

To all the above mentioned issues, the proposed solution sounds to be very important in order to adapt to the changing climate, keep producing with very little damages to the environment and to keep the agricultural emissions lowered in the country.

Better intercrops are required in order to enhance the three aspects of CSA mainly focusing on food security and climate change adaptation. It is for example the intercropping of maize and beans. Seran and Briantha (2010) made a summary of several researches carried out on maize intercrop with other crops. They showed that maize and beans intercrop is better that sole crop growing. Legumes fix nitrogen from the atmosphere which reduces the competition of soil nitrogen with maize. It also increases yield (mainly of maize component) compared to sole cropping and enhance the land use efficiency. Especially, the agroforestry system at the border of each plot is suggested due to its several benefits including its contribution to environmental protection earlier discussed in the introduction. Gliessman (2007, pp. 246) showed that agroforestry "allows more efficient capture of solar energy, enhance nutrients uptake, retention, and cycling; and maintain the system in dynamic equilibrium" and stabilize the number of pests and their predators. FAO soils bulletin 70 (1996) has studied the role of agroforestry system in Rwanda. It showed that 200 perennial trees per hectare such as *Grevillea robusta*, *Cedrella serrata* and *Polyscias fulva*, grown inside or around the fields are able to provide nice mulch from 1 to 4 t/ha/yr of leaves and twigs and to provide the require firewood for a household. This bulletin indicated that planting hedges of *Calliandra calothyrsus*, *Leucaena leucocephala* or *diversifolia*, or *Cassia spectabilis*, at every 5 to 10 m can produce 3 to 9 t/ha/yr of leaves used as excellent fodder or applied as green manure and 2 to 7 t/ha/yr of firewood; Apart from taking up nutrients from deeper soils by deep rooting species and fixing atmospheric nitrogen by nitrogen fixing species, It showed that by pruning the hedges 3 times per year, provides '75 to 130 kg/ha/yr of nitrogen, 2 to 20 kg of phosphorus, 20 to 60 kg of potassium, and similar amounts of calcium and magnesium, depending on the richness of the soil in these elements' (FAO, 1996) are provided to soil which is a significant amount nutrients closer to 10 tons of farm manure. It also proved that apart from producing a considerable amount of biomass, it reduced at great level the runoff and soil loss.

Basing on the above data provided by FAO (1996), and by considering the average farm size of 0.45ha in Musanze district, if the contour trees such as *Grevillea robusta* are used, about or more than 90 trees will be planted on this small size which may produce mulch from 0.45 to 1.8 t/ha/year and between trees, anti-erosive crops such as napier grass will be grown which will provide additional amount of fodder for livestock. Also if hedgerows at every 5m to 10m of calliandra or leuceana species are used as it is described in FAO (1996) shown above, about the half of biomass (which can be used as fodder or green manure), firewood and nutrients will be obtained, which will significantly reduce the dependency on external inputs.

However, it has proved that even if there is better control of soil erosion and runoff a significant production of biomass, the crop productivity under agroforestry in Rwanda still requires additional mineral amendment in order to increase production (FAO, 1996).

4.1.3. Economic resilience

Due to the low ability of Rwandan farmers to get access to improved inputs, the government offers them on a contract of paying back after the harvest (Ministry of Agriculture and Animal resources, 2011). However due to poor infrastructures, their distribution is not appreciated by farmers and the low price given on produce at the harvest make the payment so difficult as the money obtained from selling produces is sometimes lower than the investment (Huggins, 2012). One reason could be the absence of a stable market of produce and the lack of post harvest handling and storage facilities. There is too much supply at the harvesting time which pushes farmers to accept low prices before their products are lost due to damages and later the demand becomes bigger than supply which pushes to importation and which is always followed with high prices. Apart of these after harvest issues, incidences of on-farm loss have occurred in the country. Mainly it is due to weather events such as heavy rainfall and strong winds but also the diseases incidences, droughts and false seeds have occurred in some districts which has led to severe losses of crops. Farmers growing a single crop on their farm are more vulnerable to these events. Growing one crop for a household is considered as uneconomic as almost all the farmers find what to cook from their farm and one single crop is not able to generate all the food needed by a household (Huggins, 2012; Cantore, 2011).

These challenges make the agricultural sector less profitable and could be identified as an occupation for people without any other opportunity for surviving.

For the above mentioned issues, even if the national production of the selected food crop shows an interesting increase (figure 4), it is important to make clear that crop diversification is still needed to help first the family diversify its food products but also to reduce the risk of failure and environmental degradation above discussed. Cantore (2011) called the current economic development as 'sustainability in short run' where long term sustainability must be prepared to ensure a better future to the next generations as it is the purpose of sustainable development (FAO , 1992). The proposed solution will not only contribute to ensure food security but also it will contribute to improving the economic status. It will reduce expenses on buying and transporting fertilizers and will provide additional benefits such as fodder for animals, firewood, and timber. A great importance can be enjoyed by farmers in pyrethrum growing zones where their 40% of land must be under pyrethrum cultivation as indicated by Huggins (2012). He proved through different interviews and calculations that pyrethrum cultivation is uneconomic to farmers where he found that the revenues from this plant is between 5 to 28% the revenues of potatoes.

Diversified systems are helpful to SSF as they lead to effective land use and productivity. Seran and Briantha (2010) showed that there is efficient land use and better land productivity when maize is intercropped with other crops such as cassava and pumpkins. This is in agreement with a research carried out by Tamado, *et al.* (2007) using double intercropping of maize and beans in Ethiopia where the yield of beans was reduced in intercropping than in sole cropping but the Land Equivalent Ratio (LER) was greater than 1 and productivity increased from 6 to 66% generally; the same trend was proven by Morgado and Wiley (2008) in the semi-arid areas of Brazil. The intercropping of potatoes (Irish potatoes) with beans and maize either by strip cropping or row cropping has been proved to produce lower yield of potatoes and to reduce the nets profits in Pakistan (Farooq, *et al.*, 2010). However it seems like this study focused on the yield and economic benefits of potatoes only as another study conducted in Kenya where the yield of potatoes grown alone, maize intercropped with potatoes, and purple vetch used as green manure in potatoes showed that there were about similar results in sole crop and in intercrop with vetch, while maize intercrop reduced the yield of potatoes but the overall revenues well better in intercrop as maize yield boost the reduced yield of potatoes, but many small scale farmers adopted the intercrop with vetch as it does not require money for buying fertilizers (manure in maize and chemical fertilizers in sole cropping) and for their transport (Mureithi *et al.*, 2003). Depending to what is considered as main crop in the intercrop of maize with potatoes; Jamshidi, *et al.* (2008) proved that the intercrop of 75% of potatoes with 25% of maize gave higher yield of potatoes while a ratio of 1:1 was better for high yield of maize. This study showed that at all types of ratio, the LER was greater than 1.

4.1.4. Social well-being

Even if Musanze district is ranked the third richest district in Rwanda with 79.9% of people classified as non poor while the remaining 20.1% include poor and extremely poor people (National Institute of Statistics of Rwanda, 2012); this 20.1 % is a big proportion to take into consideration and many people in this group are mainly SSF or wage at farm whose food basis comes directly from farm. It is in this group where almost malnourished children are found (Musanze District, 2014). The district has launched different plans to eliminate malnutrition such as taking weight and height measurement in all children under five years old, teaching families how to prepare a complete meal, and having a home garden (Musanze District, 2014). In the home garden, families grow mainly different types of vegetables needed at home but this diversification could be enhanced by crop diversification in farms sothat people find a variety of other food crops required for health. By reflecting to the predicted scenarios, It may happen that Rwandan fall into the pessimistic scenario where the population is expected to double the current, its associated drop in GDP and increase in number of malnourished children (table 2). This can lead to more land scarcity and the monoculture system will not be able to produce the variety of food required for a good health. Promoting crop diversification both in home garden and at farm by focusing on legumes cultivation could reduce this issue in the future. Rwandans considers beans as an important component of a meal for every household or meat especially for poor families. In the case of Musanze district, a meal is considered as food when it includes beans (a general answer provided by children in the area, when they are asked about what they have ate at home). This proves how legumes are of high importance in the Rwandan society.

As agricultural sector is not so benefiting, some people mainly male choose to do other type of activities such as off-farm wage including wage in construction sector. This proves why in Musanze district, a grand proportion of female (83%) is more engaged in this sector compared to male whose percentage is only 49% (including both independent farmers and wage on-farm) (National Institute of Statistics of Rwanda, 2012). In the cultural aspect of Rwandans, women have the responsibility of taking care of what to cook in their family and the financial means are mainly on the head of men. This issue pushes women to do agricultural activities as a way to survive and to maintain the livelihood of their households while men do different activities in order to rise the income of their household. With the proposed solution, the rate of men involved in farming could increase as some work like tree pruning require the involvement of strong person (men). Legumes, especially deep-rooted species have the ability of reducing water pollution (Jensen, *et al*., 2012) which will save the lives of many people exposed to effects of unimproved water use.

4.2. The proposed solution together with other alternative practices towards CSA

Stockholm Resilience Center (2015) has shown that among the nine planetary boundaries, four of them have currently crossed their safe operating space. These are biosphere integrity, biogeochemical flows, climate change and land-system change. Before the improvement and changes made on planetary boundaries were published, Röckstrom, *et al.* (2009) had shown the planetary boundaries with a safe operating space where three of them had transgressed their safe operating space, (figure 2). These were biodiversity loss; nitrogen cycle and climate change. Researchers have then started to think on how human can cope with these changes. For this, Beddington, *et al*. (2012) has shown three alternative ways to produce food in terms a changing climate in order to maintain or make bigger the safe operating space (Figure 16). It shows that today, food is produced out of the safe space and that to keep in the same way of producing will keep production out of this safe space in the future (figure 16. A). By changing diet and reducing food waste, the global population food needs can be covered which enlarge the safe space (Figure 16. (1)). The safe space can be bigger also by mitigating the greenhouse gas emission from agriculture (Figure 16. (2)). (Figure 16.(3)) shows that if the two first options are not fulfilled, it is then possible to adapt to climate change, to improve yields and promote efficiency use of resources which will help to be back in the safe space.

The CMC proposed is first located in the third option which promotes adaptation and improving yield and enhancing efficiency, but then secondly it contributes to the reduction of greenhouse gas emission as it helps to reduce the dependency on external inputs mainly fertilizers and the agroforestry system helps in carbon sequestration. This system can be useful first in many other developing countries where food security is indispensable to deal with and where climate change have or will have severe effect on food production systems in the coming decades. Mixed farming systems are recognized to be very useful to people in marginal areas as they help to efficiently use natural resources such as land, water, nutrients and solar radiation, to reduce the risk of failure and to reduce pests and diseases (Altieri, 1995; Altieri, 2002). Secondly, in developed countries where apart from high agricultural emissions, other forms of emissions are also high and whose major contribution to CSA is to promote greenhouse gas mitigation.

The proposition of Beddington, *et al*. (2012) agrees with the five solutions proposed by Foley (2011) towards feeding the world with low environmental damages. These solutions are "(1) Stop expanding agriculture's footprint, (2) Close the world's yield gaps, (3) Use resources much more efficiently, (4) Shift diets away from meat and (5) reduce food waste"(Foley, 2011).

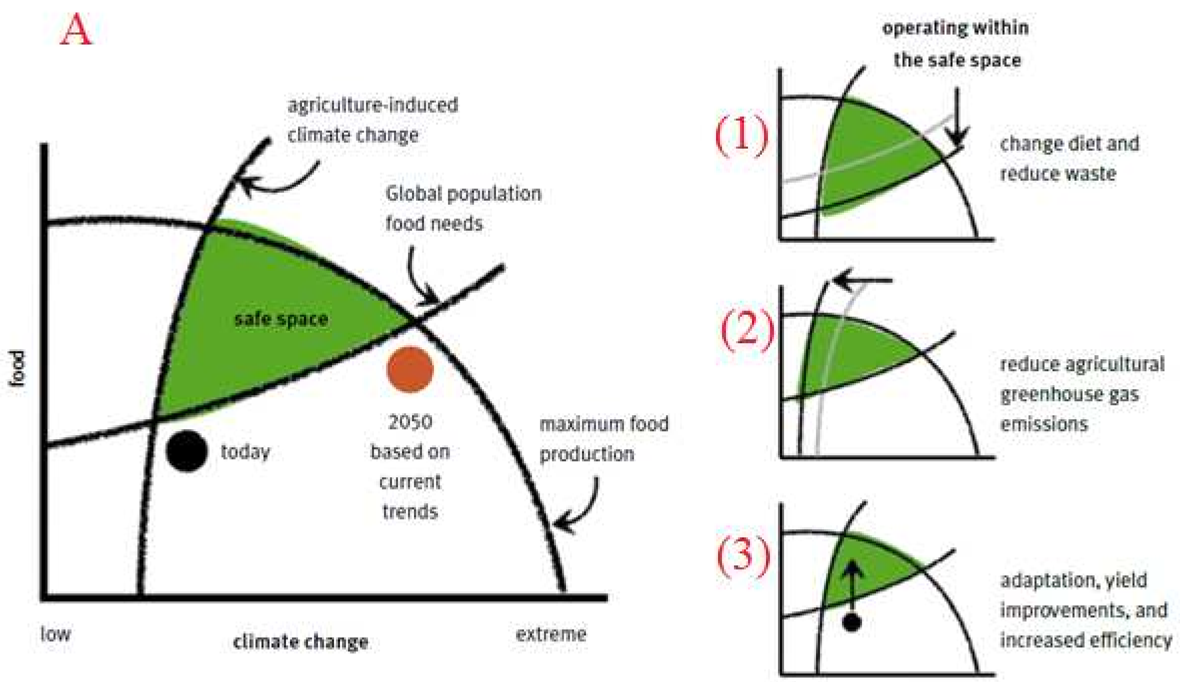

Figure 16: Safe operating space for interconnected food and climate systems. Source: (Beddington, *et al*., 2012).

These five solutions once implemented all together could rise "the food availability by 100 to 180 percent, while significantly lowering greenhouse gas emissions, biodiversity losses, water use and water pollution" (Foley, 2011). Koohafkan, *et al* (2012) argue that an agricultural system that can deal with the climate change is the one that is able to reach high productivity through the promotion of high diversity and efficiency where these can be achieved through closed systems (low external inputs), enhancing high level of recycling and animal integration into agriculture. According to the population and income scenario (Nelson, *et al*., 2010), both suggestions from Foley (2011) and Beddington, *et al*. (2012) consider the baseline scenario where the world's population is estimated to 9 billion in 2050. However, it is also important to plan for the pessimistic scenario: 10 billion. For this issue, enhancing family planning (reducing birth per women) mainly in the developing countries, where this rate is high, could reduce the evergrowing population of the world and its associated effects.

5. Conclusion and recommendations

This thesis aimed at redesigning a farming system which can help to get good yield with low environmental damages in Musanze district of Rwanda. The results showed that currently, there are two farming systems in every district of Rwanda: mixed system, older, done for subsistence and which took a high percentage of farmers; and monoculture, which is being promoted by the government. Both systems are exposed to climate change as they are done in an area more vulnerable to floods and landslides enhanced by overexploitation of land and low soil protection measures. These cause severe soil and agricultural losses followed by environmental damages. Due to high population density and the future climate change scenarios, the older farming is suggested as an improvement but in a modern form (CMC) towards a CSA: (1) mixing within farm by selecting species which can co-exist or have low competition and using proper crop density and spacing. For this, row intercropping or strip cropping are given as examples all together with (2) trees/shrubs and/or anti-erosive crops at the border of each farm. As the government has been identified as a key initiator of any change, the proposed solution can be implemented by simply shifting from a top-down and instrumental approaches to the enhancement of participation of all stakeholders in decision making toward long-term sustainability.

It may happen that mixing within the farm is not appreciated due to the focus of increasing agricultural production. For this, using cover crop is suggested as it helps to reduce soil erosion, improves soil properties and fertility (FAO, 2011); or to adopt a conservation agriculture described in the introduction section. These two alternatives will help to significantly reduce the erosion as a key challenging issue for farmers in Rwanda and to maintain soil cover on farms.

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APPENDIX -Fact sheet

Improving the existing farming systems toward a climate smart agriculture in Musanze District of Rwanda

Stephanie Uzamukunda

This fact sheet is mainly addressed to the governmental officials, advisors, extensionists and other public / private actors in agricultural sector in Rwanda. This is due to the fact that they play a key role in decision making and implementation of any plan, project/program or policy aiming at developing agriculture in Rwanda and that farmers' participation as the key beneficiaries is sometimes ignored due to their limited knowledge and skills.

1. Existing farming systems

Figure 1: Boundary between the Volcano National Park, settlements and agricultural activities. Source: (Rwanda Environment Management Authority, 2011).

1. Mixed intercropping: Old farming system. It has been practiced since a long time up to now. In this system, farmers broadcast different types of sowing materials (potatoes, beans, maize,...) on the same farm without taking care of planting density, spacing, competition and compatibility of species. It is done mainly for subsistence.

2. Monoculture system: recently promoted by the government through its programs aiming at developing agriculture sector and turning agriculture into a profitable activity. These programs include the CIP with its sub-programs among others land use consolidation program, crop regionalization, extension services and inputs (mainly chemical fertilizers and improved seeds) provision. This system enhances the cultivation of a single crop on the farm which can be rotated with other after its harvest.

2. Why changing the farming systems?

With the effects of climate change already visible in Rwanda including heavy rainfall, droughts, pests and diseases incidences in some districts, especially floods and landslides incidences in the Western province and Northern province where Musanze district is located, it is very imperative to act as soon as possible in order to reduce its consequences and to contribute to a climate-smart agriculture (CSA).

Farmers in Musanze district experience floods or landslides probably every year due to heavy rains and strong winds which causes mainly torrential rains to flow from the volcano national park. These rains have several damages among others taking lives of human and livestock, crop destruction and washed away, severe soil erosion, houses and infrastructure destruction and serious environmental damages.

Figure 2: Field of beans destroyed after heavy rains followed by floods in the end of April, 2015. (Picture taken by Alphonsine Mukamuhirwa).

This is enhanced by human activity especially through agriculture which increases the gravity of such events. Following are some of the causes. Apart from the topographic aspect (mountainous region characterized by a hilly and sloppy aspect) and the torrential rains from the volcano, the deforestation and the evergrowing population makes land availability so scarce where the average farm size is estimated to 0.45ha in Musanze district (National Institute of Statistics of Rwanda, 2012). This puts too much pressure on land and the overexploitation has exposed soils to reduced fertility. The low soil erosion control measures, weak farming systems and practices on unprotected soils with the overexploitation of land, have enhanced soil erosion hence reducing soil fertility and crop yield. Another issue is that the drainage system is very weak and sometimes the channels are full of sediments, which makes water to overflow and spread in the farms around. All these issues make farmers in Musanze district to be vulnerable to floods and landslides.

The future predictions show that the number of population, climate change and its associated effects will continue to increase in Rwanda, where the population is predicted to double the current one while a dryer or wetter climate is expected depending to the type of scenario used, with an average temperature increase from 1 to 1.5^{o}C mean (Ngoga *et al.*, 2013). These will worsen the problem of land availability, but also the agricultural productivity is expected to be generally reduced in the whole country. These will generate more environmental and socio-economic damages which may severely affect a very large number of farmers as more than 91% are famers in Musanze district. All these issues require a quick action to counteract the possible negative impacts which may result from these changes in order to enhance a CSA.

3. What is a climate-smart agriculture?

CSA is "an approach for responding to climate variability and change while providing the triple wins of food security, climate change adaptation and mitigation" (UCDavis, 2013). The purpose of CSA is to achieve food security, adapt to climate change and variability and reduce or remove the greenhouse gas emission by developing and adopting efficient practices, policies, institutions, research, technology and finance helping to reach these three components of CSA (UCDavis, 2013; FAO, 2013). The implementation of this approach requires collaboration and participation of multiple stakeholders and disciplines, sciences, research and technology all enhanced by a political willingness and economical orientation change toward an effective management of resources, inputs and outputs of agriculture for a better future under a changing climate (FAO, 2013).

4. Complex mixed cropping as a solution for improvement

The complex mixed cropping proposed include the older crop mixing practice but in a modern form. It can be made by (1) *strip cropping* (insider figure 3) with *trees/shrubs and/or anti-erosive crops* (boundary of figure 3) or (2) *row intercropping* with *trees/shrubs and/or anti-erosive crops* (boundary of figure 3).

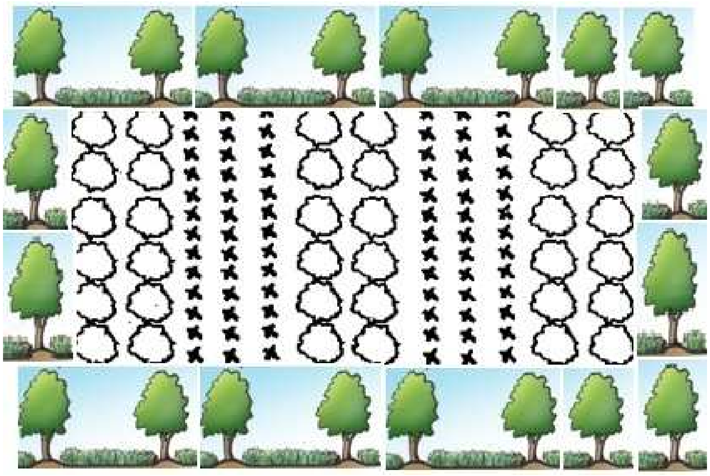

Figure 13: Proposed cropping system: A complex mixed cropping. Source: http://nac.unl.edu/buffers/guidelines/4_opportunities/5.html;http://www.fao.org/wairdocs/ilri/x5545e/x5545e04.htm

Strip cropping is done by growing different crops in the same field and in the same growing season. It requires making strips of 3m to 9m large of varied crops like maize, beans, potatoes and vegetables. It has several benefits among others enhancing crop rotation, diversifying products, improving soil fertility, reduced competition among intercrops, easy to manage and produce residues which are used as soil cover (FAO). *The row intercropping* is a form of intercropping where the main crop is grown on rows and the other crops (such as cover crops) are broadcasted in between or both intercrops (the main and other crop) are grown on rows (FAO). This system has the same benefits with intercropping but also it can provoke a competition among species for resources. Both forms (strip intercropping or row intercropping) are proposed for the insider of the farm. For the border, this study proposes planting perennial trees and/or shrubs with anti-erosive crops between them or using dense shrubs only. The main purpose is to control erosion but also this species produces feeds for animal or farmers can make compost or use them as green manure and they are a very good source of carbon sequestration.

5. Some of the expected benefits

While many research conducted on crop mixture show that a better mixture has more or equal production in comparison to sole cropping, mixing crops also help to diversify farm outputs hence reducing malnutrition, help to efficiently use land, water, nutrients and solar radiation, building soil fertility and reducing soil erosion. Especially, FAO soils bulletin 70 (1996) has studied the role of agroforestry system in Rwanda. It showed that 200 perennial trees per hectare such as *Grevillea robusta*, *Cedrella serrata and Polyscias fulva*, grown inside or around the fields are able to provide nice mulch from 1 to 4 t/ha/yr of leaves and twigs and to provide the require firewood for a household; Planting hedges of *Calliandra calothyrsus*, *Leucaena leucocephala* or *diversifolia*, or *Cassia spectabilis*, at every 5 to 10 m can produce 3 to 9 t/ha/yr of leaves used as excellent fodder or applied as green manure and 2 to 7 t/ha/yr of firewood; Apart from reducing at a great level the runoff and soil loss, taking up nutrients from deeper soils and fixing atmospheric nitrogen by nitrogen fixing species, pruning the hedges 3 times per year, '75 to 130 kg/ha/yr of nitrogen, 2 to 20 kg of phosphorus, 20 to 60 kg of potassium, and similar amounts of calcium and magnesium, depending on the richness of the soil in these elements (FAO, 1996) are provided to soil which is a significant amount of nutrients closer to 10 tons of manure.

6. Feasibility of implementation

This solution was proposed in order to solve some of the conflicts and challenges rose from previous programs targeting at agriculture professionalization and increasing yield: Farmers have been resisting to CIP and its associated sub-programs due to lack of crop diversification and due to forced implementation where benefits were considered to be enjoyed by the government and other stakeholders such as inputs providers and retailers (Ansoms &Mckay, 2010; Huggins, 2012). Farmers' willingness to implement this solution is not doubted as their wish is to diversify farm outputs.

For this, the government is requested to:

- Change first its economic orientation. Not only to think about increasing yield of some prioritized crops, but to focus on farmers' need of diversification.
- Facilitating its implementation and enhancing participation.

This will help to maintain and diversify yield hence leading to food security. It will also help to control soil erosion to a great extent, to efficiently use natural resources and help to carbon storage and GHG mitigation in this changing climate.

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