# Identification of Potential Niches for Soybean cultivation in Farming systems of Eastern and Southern Rwanda


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## Abstract

The research was conducted within N2Africa project; a large scale, research project focused on putting nitrogen fixation to work for smallholder farmers growing legume crops in Africa. The aim of our research was to explore niches for grain legumes, specifically for soybean intensification among different smallholder farms in Eastern and Southern Rwanda. Farmers were classified into different types based on regional specific resource endowment indicators and following the governmental household typology ''Ubudehe''. Data were collected in Bugesera and Kamonyi districts representing Bugesera and Central plateau Ago-Ecological Zones of Rwanda. Socio-economic data were collected including farm size, livestock ownership, off-farm income, labour use, soybean production objectives and perceived constraints. Among biophysical, data on soil and plant were taken. Data on market opportunities were gathered. Soybean competitiveness with other crops in terms of $N_2$-fixation, soil fertility, food security and economic benefits were assessed. The analyses were performed at farm level to get an insight on the potential of soybean production to improve income, nutrition and soil fertility across different farm types. Furthermore, farmers' perceptions gave an insight in soybean production objectives and constraints among different farm types in different AEZs. In current production system, soybean was a minor crop at both sites and did not seem to compete with other crops in terms of yields and income. The crop was found to be grown on less fertile fields, and on little land area compared with other crops. In terms of productivity, average grain yield was 483 kg $ha^{-1}$ while bean had an average grain yield of 780 kg $ha^{-1}$ in Bugesera. In Kamonyi, soybean average grain yield was 689 kg $ha^{-1}$ while beans had 757 kg $ha^{-1}$. Higher N content in above ground DM was obtained in soybean of Kamonyi with an average of 50 kg N $ha^{-1}$ while bean N content was 34 kg N $ha^{-1}$. In Bugesera, N content in above-ground DM of soybean was less compared with bean with 32 kg N $ha^{-1}$ and 39 kg N $ha^{-1}$ respectively. Net N input from $N_2$-fixation was found to be negative for both beans and soybean. Net N input was lower in beans than in soybean in Bugesera with -26 kg N $ha^{-1}$ and -17 kg N $ha^{-1}$ respectively. The reverse was obtained in Kamonyi, where net N input from $N_2$-fixation was lower in soybean than in beans with -27 kg N $ha^{-1}$ and -23 kg N $ha^{-1}$ respectively. Field partial nutrient balances were negative for soybean in Bugesera, even if the stover were to be returned to the field. For beans negative balances were observed in all farm types of Bugesera, except farm Type 4. In Kamonyi, soybean gave positive balances for all farm types and balances were higher when stover were to be returned to the field. Beans gave also positive balances. In terms of food security, soybean came first in protein production per unit area in all farm types. In Kamonyi, agro ecological conditions were favourable for soybean and market opportunities were available. In Bugesera, drought occurrence led to the adoption of groundnuts rather than soybean due to the fact that groundnut is more drought tolerant and has higher market value than soybean. In this study, soybean was found to be consumed more by resource poor farmers than resource rich farmers. Resource poor farmers constitutes a great number of the population, thus should be the focus of research efforts given the crop's nutritional merits. Resource rich farmers have more opportunities to expand soybean production than resource poor farmers. These farmers will not eat soybean for various reasons such as unacceptable taste. For these, soybean cultivation is seen as appropriate only for commercial farming where the crop can be used for industrial processing. Food made from soybean processing was found to be the most acceptable in cities. To date it is not yet clear the importance of soybean in Rwandese farming systems in terms of income. In the future, soybean can become a major crop in Rwandese farming systems given that that the market is expanding. This study highlights that soybean niches are farm type and AEZ dependent.

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# 1 Introduction

## 1.1 Background

Legumes have been part of the human diet since the early ages of agriculture and many legume species are still irreplaceable source of dietary proteins for humans. Fresh immature pods and grain provide a green vegetable and dry seeds are cooked in various dishes. The protein-rich legumes as a complement to cereals make one of the best solutions to protein-calorie malnutrition, particularly in developing countries (Burstin, et al., 2011).

About 1.1 million people in the world live on less than one US dollar per day and 325 million are found in sub-Saharan Africa (von Braun and Rosegrant, 2004). In Rwanda, three quarters of the population, estimated at about 9 million were found below the poverty line (Rwanda, 2004). Vinck *et al*. (2009) reported that poverty, food insecurity and malnutrition exist among all livelihood profiles in Rwanda. The government of Rwanda has put in place policy measures on the stabilisation of food supplies by prioritizing and promoting the growth of food crops that have an impact on food security. Major food crops are rice, maize, beans, sorghum and potatoes, while cash and export crops are tea, coffee, and pyrethrum (MINAGRI, 2006). Despite the improvement in the production of commercial cash crops, food insecurity remains a real concern and the consumption of calories and proteins per capita has not registered significant improvement in recent years (Bizimana, 2007). Food insecurity is particularly pronounced in the most vulnerable groups including agriculturalists-low income, agro-labourers, and marginal livelihoods as mentioned by Vinck *et al*. (2009). These groups account for 46 per cent of the total population. Agriculturalists-low income and agro-labourers groups depend uniquely on agriculture to sustain their livelihood and income.

It is known that animal products (meat, milk and fish) serve as sources of high quality protein and essential amino acids such as lysine, which is one of 20 essential amino acids and has been identified to be the key limiting amino acid in the human diet (FAO/WHO, 1991; Pellett and Young, 1998; Young, et al., 1989). Animal foods on average contain 85 mg lysine $g^{-1}$ protein, cereals contain only 30 mg lysine $g^{-1}$ protein, and legumes contain 65 lysine mg $g^{-1}$ protein and amino acids (Serraj, 2004). This highlights the importance of legumes in human nutrition and specifically for poor people whose access to animal products is limited. In recent years, Rwanda has seen an increase in the number of cattle. The increase in cattle numbers has contributed to a significant increase in milk production and subsequent increase in average consumption of milk per capita from 6.8 L $year^{-1}$ in 1999 to 20 L $year^{-1}$ in 2007 (MINAGRI, 2008). Although production of livestock products has increased, demand still outstrips supply, especially for milk and eggs, which contribute to food insecurity (lipids and protein intake) (REMA, 2009). As agriculture is recognised in the Economic Development and Poverty Reduction Strategy (EDPRS) as one of the priority sectors that will both stimulate economic expansion and make the greatest contribution to poverty reduction and food security, the adoption of legumes may be regarded as a good option to provide protein to smallholder farmers who are not able to access animal products. Although legumes are very important crops, they have a rather low profile in Rwandan farming systems when compared to cereals and tubers.

Besides nutritional role of legumes, they are also useful as rotation crops that improve soil fertility through nitrogen fixation. According to Mpepereki and Pompi (2002), nitrogen remains the single most limiting nutrient for crop growth in most of developing countries; hence exploitation of biological nitrogen fixation offers a unique opportunity to harness "free" fertilizer from a relatively low cost technology. Therefore, grain legumes intensification may be regarded as one of the means to alleviate protein resource scarcity and declining land productivity in Rwandan farming systems through nitrogen fixation. For instance, soybean has been shown to respond well to inoculation with appropriate strains of rhizobia and fixes large quantities of N under field conditions.

The benefits of soybean (*Glycine max* [L.] Merr.) over other grain legumes commonly grown by smallholders, such as groundnut (*Arachis hypogaea* L.), cowpea (*Vigna unguiculata* [L.] Walp.) and common bean (*Phaseolus vulgaris* L.), include lower susceptibility to pests and disease (Giller, et al., 2011a; Mpepereki, et al., 2000), better grain storage quality, and a large leaf biomass which gives a soil fertility benefit to subsequent crops (Mpepereki, et al., 2000). As reported by Giller *et al.* (2011a), soybean can tolerate up to 30 per cent defoliation without significant yield loss, above which economic yield loss occurs and insecticides are needed. This shows the suitability of soybean cultivation for smallholder farmers to whom the access to chemical inputs is a problem. In addition, soybean constitutes a high quality but inexpensive crop protein and can be used to produce cooking oil (Misiko, et al., 2008). Besides, soybean was identified as the crop with a potential to address the need for diversifying the cropping systems, which could assist in overcoming the pervading soil fertility constraints and could provide smallholder farmers with an opportunity to earn income while also addressing the nutritional security of households (Giller, et al., 2011a). Furthermore, soybean has a major potential to benefit smallholder farmers in sub-Saharan Africa where soil fertility is extensively depleted due to a combination of increasing population, poverty and inherently poor soil (Vanlauwe and Giller, 2006).

**Aim and Relevance**

In Sub-Saharan Africa, grain legumes are seen as meat for poor farmers due to their rich protein content and the low prices of pulses compared with real meat. High productivity of pulses becomes vital as most of poor people depend on pulses for protein supply to meet their nutritional and health needs (Chianu, et al., 2011; Chianu, et al., 2009). However, smallholder farming systems are often constrained by low productivity. The low yields pronounced in grain legumes are associated with declining soil fertility and reduced $N_2$-fixation due to biological and environmental factors (Amijee and Giller, 1998; Chianu, et al., 2011; Dakora and Keya, 1997). Although many sub-Saharan countries have a growing need for fertilizers to enhance crop yields (Morris, et al., 2007; Mugabe, 1994; WorldBank, 2008), the majority of African smallholder farmers are not able to afford the high mineral fertilizer prices (Yanggen, et al., 1998).

In Rwanda, most farmers are smallholders and many earn less than US$ 1 per day. More than 60 per cent of households cultivate less than 0.7 ha of land, and more than a quarter cultivate less than 0.2 ha (REMA, 2009). The standard of living is strongly related to the size of landholding, with those holding the least land generally being the poorest (EDPRS, 2007). Although food insecurity remains a real concern and the consumption of calories and proteins per capita has not registered significant improvement in recent years, major sources of proteins remain insufficient (Bizimana, 2007). Low cost and sustainable technical solutions compatible with socio-economic conditions of smallholder farmers are needed.

Several studies have been conducted and tried to assist farmers on protein resources in Rwanda. For instance, Hishamunda *et al.* (1998) compared the ability of small-scale aquaculture and crops production in supplying protein to rural livelihood and showed that fish production was the most expensive way of producing protein and soybean was ranked to be the most cost-effective. The study by Nyinawamwiza *et al*. (2007) showed the potential of soybean in supplying cheap protein meal to the fish. All these show the efficiency of soybean as source of protein for human food and animal diets. In addition, soybean can also be processed locally in many products and as Rwanda being a land locked country; the costs of importation make local processing economically competitive. Studies conducted on soybean response to inoculation in Rwanda before 1990 showed the potential of soybean in fixing N which could result in improved farming system.

Although soybean has a great potential for smallholder farmers, it is not well known in most parts of sub-Saharan Africa. Compared to common bean, soybean is a minor crop in the farming systems of Rwanda in terms of acreage and consumption. It however constitutes one of the crops that the government of Rwanda is currently relying on to achieve economic growth because of its high nutritional value, adaptability to the country's agro-climatic zones, and potential to respond to organic and mineral fertilizer inputs (ROR, 2004). In the framework of promoting oil crops in Rwanda, the Strategic Plan for Agriculture Transformation (SPAT) states that interventions will be concentrated on soybean with the following actions: (i) increase the production capacity of good quality seeds and of inoculation for soybean (Rhizobium); (ii) develop programs of development research on mineral fertilization in order to increase the production potential even in regions having acidic soils; (iii) support the development of transformation units of soybean into flour and other derived products (milk and tofu) and , (iv) make the consumption of products based on soybean popular (ROR, 2004). However, the implementation requires the knowledge with regard to farmers' constraints and opportunities in soybean production. Thus, the identification of potential niches for soybean cultivation would contribute to the success of the implementation of soybean promotion by the government.

This study conducted within the framework of N2Africa project, aims to identify potential soybean niches for three major reasons. First, given that soybean is not a traditional crop in Rwanda, that is, it is not common in major farming systems and in the normal diet of majority of Rwandans. Second, the lack of information on whether soybean production is affected by difference in farmers' resource endowment, the detailed information on the extent at which soybean is produced and used within household and whether its intensification could result in improvement of smallholder farmer's livelihood is still insufficient. Third, soybean incorporation either in rotation or intercrop with a cereal or other crops constitutes one of the low-cost soil fertility management options to smallholder farmers. Furthermore, there are several non-governmental organization projects targeting soybean production and contributing to increased knowledge and skills for soybean growers. e.g. Clinton Hunter Development Initiative-funded project, Catholic agencies (CARITAS) and TRONCAIRE-funded, Duhamic-ADRI and Conseil Consultatif des Femmes (COCOF). The identification of soybean niches as affected by different farm types is urgently needed as an *ex-ante* assessment for soybean supporting initiatives, specifically N2Africa project, in order to allocate best fit extension and technological services to farmer and guide those non-governmental organizations to tailor and enhance their extension technologies by targeting those farmers that are likely to benefit from the technology.

In the present study, we applied tools that are developed for detailed farm characterization with N2 Africa project on the basis of NUANCES approach. As indicated by Giller *et al.* (2011b), the NUANCES (Nutrient Use in Animal and Cropping Systems-Efficiencies and Scales) framework is built on four steps: describe, explain, explore and design. This framework provided us with tools to describe the current extent at which soybean is produced and used at household level, the constraints and challenges in soybean production. It guided the understanding production objectives, orientation across different farm types, thus allowing to explore potential niches for soybean intensification and to design possible interventions for intensifying soybean cultivation taking into consideration the differences in farmers' resource endowments.

### N2Africa project

The improvement of grain legume productivity has been a major objective of many national research programmes in the tropics: the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has responsibility for research on groundnut and pigeonpea and is the base of the Asia grain legume improvement Programme, research on chickpea is the joint responsibility of the International Centre for Agricultural Research in the Dry Areas (ICARDA) and ICRISAT, the Centro Internacional de Agricultura Tropical (CIAT) has responsibility for *Phaseolus vulgaris*, the International Institute of Tropical Agriculture (IITA) has conducted research on cowpea and soybean (Giller, 2001). Recently, N2Africa, a large scale, research project focused on putting nitrogen fixation to work for smallholder farmers growing legume crops in Africa. The presented research was conducted within the framework of N2Africa project. N2Africa project is aiming at (1) identifying niches for targeting nitrogen fixing legumes, (2) testing multi-purpose legumes to provide food, animal feed, and improved soil fertility. Its rationale is to raise average grain legumes yields, increase average biological nitrogen fixation (BNF) and increase income generation for smallholder farmers. It seeks putting legume technology to work among smallholder farmers with emphasis on socio-ecological niches of grain legumes and the associated technologies in African farming systems, i.e. how to target the technologies in order to have a high chance of adoption by farmers (N2Africa, 2010). In Rwanda, the ministry of agriculture has merged some of its agencies to form Rwanda Agriculture Board (RAB) in order to improve services to farmers in their daily activities. RAB groups the Rwanda Animal Resources Development Authority (RARDA), the Rwanda Agricultural Development Authority and the Rwanda Agriculture Research Institute (ISAR). RAB has the general mission of developing agriculture and animal husbandry through their reform and using modern methods in crop and animal production, research, agricultural extension, education and training farmers in new technologies.

## 1.2 Theoretical framework

### Biological Nitrogen Fixation

Nitrogen fixation can contribute directly to agricultural production by providing the N of the leafy vegetative parts, pods, seeds and tubers of plants used as feed for livestock or harvested for human consumption. Nitrogen fixation is also a major source of N for agricultural soils via the N- rich residues that remain following plant harvest or grazing (Unkovich, et al., 2008 ). Symbiotic relationships between legumes and rhizobia are responsible for the largest contributions of fixed N to farming systems (Giller, 2001). Establishment of effective $N_2$-fixing symbioses between legumes and their $N_2$-fixing bacteria (rhizobia) is dependent upon many environmental factors and can be greatly influenced by farm management practices (Peoples, et al., 1995). One of the most factors limiting a legume's ability to fix $N_2$ is the absence of sufficient numbers of effective rhizobia in the soil. Fortunately, strains of rhizobia can be introduced into soil relatively simply by inoculation and, in many countries, this has been practiced successfully on a commercial scale for many years (Unkovich, et al., 2008 ). However, research had demonstrated that nutritional deficiencies induced by poor supply of available phosphorus commonly restrict legume growth and $N_2$-fixation (Giller and Cadisch, 1995).

Main environmental factors which limit BNF are soil nutrient deficiencies, or factors associated with soil acidity, large concentration of plant-available N in the soil and moisture availability (Giller and Cadisch, 1995). In many parts of the tropics, Biological Nitrogen Fixation by legumes is severely limited by phosphorus (P) deficiency and could be dramatically improved by use of P fertilizers (Toomsan, et al., 1995).

The fixed N contributes to productivity both directly, where the fixed N is harvested in grain or other food for human or animal consumption, or indirectly, by contributing to the maintenance or enhancement of soil fertility in the agriculture system by adding N to the soil (Giller and Cadisch, 1995). The ability of legumes to improve soil fertility has been explored by several researchers (Muhr, et al., 2001; Ojiem, 2006; Snapp and Silim, 2002). Biological $N_2$-fixation is an important option for improving the soil N balance in smallholder farming systems (Giller, 2001). Beneficial effects of legumes on soil fertility as well as subsequent cereal crops are well documented (Peoples and Craswell, 1992; Wortmann, et al., 1994). Although the benefits of legume N fixation to the system have been reported, N fixation differs from one legume to another and in some cases $N_2$-fixation by legumes cannot compensate for the N removed through the produce. Grain legumes have been reported to contribute to soil fertility N enrichment when the percentage of N derived from fixation is greater than or equal to the nitrogen harvest index (NHI) of that legume and when the stover is incorporated (Giller, et al., 1994; Toomsan, et al., 1995).

The contribution of a legume to soil fertility depends on the species and on the crop management and most nitrogen contribution of a legume will depend on the amount of plant matter returned to the system. According to Peoples *et al.* (2009), much of the N fixed by the legume is usually removed at harvest in high-protein seed so that the net residual contributions of fixed N to agricultural soils after the harvest of legume grain may be relatively small. Thus, the net inputs of fixed N into soils depend on the amounts of N fixed relative to the amounts of N removed in the protein-rich legume products (Peoples, et al., 2009; Salvagiotti, et al., 2008). Comparison of the percentage N from $N_2$-fixation and the percentage N harvest index gives a rapid method for indicating whether there will be a net positive or negative residual N benefit if the stover is returned to the field (Eaglesham, et al., 1982; Giller, et al., 1994; Toomsan, et al., 1995). Although there may not be a huge N input by some legumes, where rates of $N_2$-fixation are high the mining of soil N is likely to be less than that with non-legume crops (Toomsan, et al., 1995).

**Legume niches**

According to Ojiem *et al.* (2006), although legumes have the potential for improving productivity, their sustainable use is impended by the high degree of biophysical and socio-economic heterogeneity that characterizes smallholder farming systems in sub-Saharan Africa. Potential niches refer to socio-ecological niches, in other words agro-ecological and socio-economic niches. Ojiem *et al.* (2006) defines socio-ecological niche as a smallholder farmer environment fashioned by the interactions between biophysical and socio-economic factors and processes that facilitate functionality and presents to the smallholder the potential to attain desired production objectives. This is described as the type of legume a farmer wants to grow to meet his/her own production objectives and whether the prevailing biophysical and socio-economic environments and the existing institutional framework can support that choice. Socio-ecological niche is an integral of (agro-ecological factors, socio-cultural factors, economic factors and ecological factors). Agro-ecological factors influence adaptation of the legume to broad level environmental conditions. Socio-cultural factors (i.e. community restrictions and incentives) have a significant influence on technology adoption. Economic factors influence farmer behaviour with respect to technology adoption decisions, while ecological factors operate at the local level and influence adaptation to the local environmental conditions.

Besides, variations in farm soil fertility are significantly influenced by farmers' soil fertility management and resource endowment has an impact on the management and soil fertility (Shepherd and Soule, 1998; Tittonell, et al., 2005b). To be adopted by farmers, a farming technology must fulfill farmers' needs and find its suitable socio-ecological niches on-farm (Ojiem, 2006). Socio-ecological niche concept is proposed as a useful framework for identifying and analysing biophysical and socioeconomic conditions likely to drive the intensification of soybean in Rwandan smallholder farming systems, to facilitate the better tailored technologies to the large heterogeneity of smallholder farmers.

Socio-ecological niche concept was used by Ojiem *et al.* (2006) in Western Kenya smallholder farming systems, where they explored the utility of the socio-ecological niche concept as a tool for facilitating legume technology development and targeting within the heterogeneous smallholder farming systems using some selected promising legume species and varieties. Ojiem *et al.* (2006) define agro-ecological factors at two scales: i) the broad scale biophysical conditions to which legume must be well adapted and he refers to these as agro-ecological factors (precipitation, temperature, solar radiation, photoperiod, soil type etc.). ii) Biophysical factors that influence the productivity of legume at farm level and he refers to these as local ecological factors. For example, poor moisture and P availability in the soil comprise important constraints to wider adoption of soybean (Misiko, et al., 2008). Farmers are not a uniform group by any means (Amede, 2004; Ojiem, 2006; Snapp and Silim, 2002). In African subsistence farming system, the food habit dictates the amount of land allocated for various crops and the type and amount of input invested per crop. Also the market value of the crop may dictate how much land is allocated for legumes. Besides, farmers' preferences are determined by their perceptions of the possible returns, and the constraints they face (Snapp and Silim, 2002). Increased adoption and utilization of legumes can be expected when farmers see clearly benefits to their farming systems (Serraj, 2004). Hence, exploitation of BNF technologies in African farming systems requires the identification of appropriate N-fixing legumes that have multiple benefits to ensure adoption by risk-averse rural communities (Mpepereki and Pompi, 2002).

**Diversity in smallholder farms**

African farming systems are highly heterogeneous: between agro-ecological and socio-economic environments, in the wide variability in farmers' resource endowments and in farm management; which means that blanket solutions for improving farm productivity do not exist (Giller, et al., 2011b). For legumes to be adopted and intensified in smallholder farming system, the diversity of farmers' resource endowment and the complexity of bio-physical and socio-economic conditions that farmers face are to be taken into account as drivers of adoption and popularization of legume. For instance, Tittonell *et al.* (2005a) distinguished five farm types in Western Kenya, based on farmers' resource endowment and production criteria. Sumberg (2002) suggests that the adoption and dissemination of legumes are affected by multiple factors, which can be nested within and defined by three conceptual factors; i) socio-cultural, political and economic factors; ii) agro-ecological factors; and iii) management at farm level. Access to on-farm and off-farm sources of income and functionality markets may be additional characteristics (Ojiem, 2006). Legume niche criteria, criteria boundaries and the process for delineation of socio-ecological niches are presented in Fig.1.

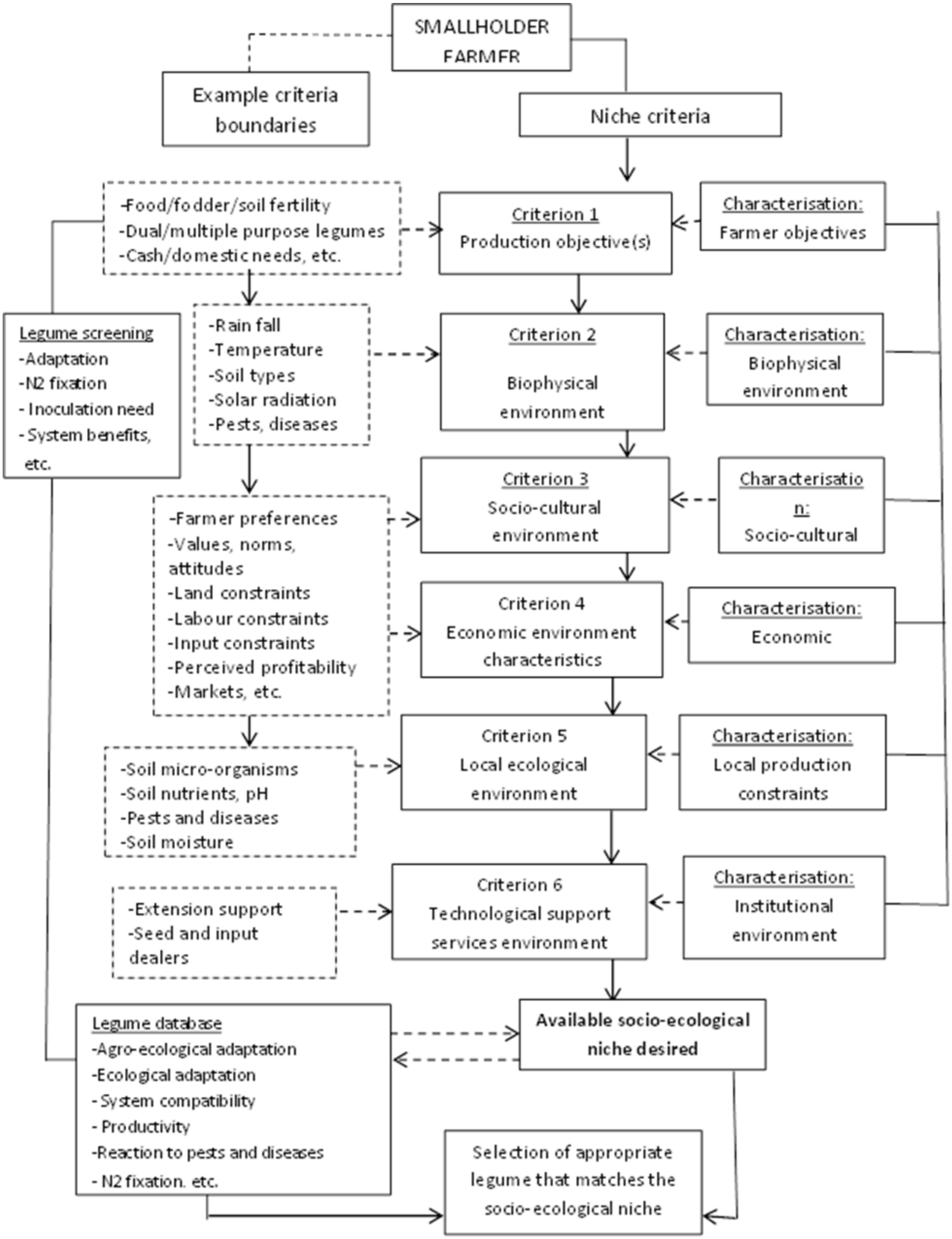



Fig. 1. Legume niche criteria, criteria boundaries and the process for delineation of socio-ecological niche (Ojiem, et al., 2006)

### 1.3 Basic information on soybean production in Rwanda

Soybean is world-wide grown scale grown on almost 100 million ha recently (FAOSTAT/FAO, 2011). The interest in soybean is due to its higher seed protein content of about 400 g/kg (dry matter basis) and an oil content of 200 g/kg which make it a desirable raw material in a huge number of food, feed and non- food applications (Vollmann, et al., 2011). As soybean yield is closely related to nitrogen availability with a linear soybean grain yield increase of 13 kg per kg N above ground accumulation (Salvagiotti, et al., 2008), N supply through biological $N_2$ fixation is of higher relevance to economic and environmentally safe crop production. Moreover, N fixation has a significant impact on seed protein content (Vollmann, et al., 2011) thus determining the value of the soybean crop harvested (Vollmann, et al., 2011).

***Trend of soybean production in Rwanda***

Soybean was introduced in Rwanda around 1930 and its adoption was very slow. The government took some measures for its promotion and intensification of production via extensions and release of seeds, its introduction in population food as well as organizing trading campaigns (Ruzindana, 2002). Although all measures were taken, its development has been very slow in previous years. Currently, The Rwandan government is trying to promote soybean production. Table 1 shows the trend of soybean production in Rwanda for the last five years.

Table 1 Trend of soybean production in Rwanda for last five years (add more years)

| Year | Area (1000 ha) | Production (1000 T) | Yield (Kg $ha^{-1}$) |
|---|---|---|---|
| 2006 | 17.5 | 15 | 843 |
| 2007 | 25 | 20.9 | 768 |
| 2008 | 30.9 | 25.5 | 805 |
| 2009 | 33 | 25.3 | 752 |
| 2010 | 35.8 | 28.3 | 791 |

Adapted from Rwanda crop assessment, 2009 and 2010; Agricultural statistics 2002-2008

The yield remains low, fluctuant and even decreasing. Although land allocated to soybean production seems to be increased, its land share compared to other crops remains negligible in Rwandan farming systems.

***Soybean varieties and seeds system in Rwanda***

Soybeans were introduced to Rwanda in 1930; its spread in the farming system of Rwanda has been very slow as it is cultivated by few farmers in middle and lower lands of the country. Research in past years on soybean started after its introduction in 1930 at ISAR Rubona. Until 1969, main works consisted of trials of comparisons of different varieties released in the country and on planting densities. The first soybean inoculation trials were conducted at Rubona in 1933 but it was only in 1968 that works on systematic studies started. From 1935 to 1975, 336 varieties were tested at Rubona. Currently cultivated soybean varieties are Peka 6, Bossier, Ogden, Duiker, 449/16, Soprosoy, Yezumutima, Buki and 1740-2E. Their characteristics, land suitability and yield are presented in Appendix 2.

The improvement of soybean yield planned by the government was mainly based on inoculation by *Bradyrhizobium japonicum*, use of improved varieties and improvement in production techniques. It seems that most research on soybean were done before 1994 and after that period, no data on soybean became available until recently.

**1.4 Ubudehe programme**

Ubudehe programme aims to improve the lives of citizens and promote community development from the bottom up instead of the top down. It is a community based system that assesses the financial situations of citizens living in villages throughout Rwanda, the community evaluates each household's or citizen's financial/asset situation and places it in one of six categories: vulnerable (umutindi nyakujya), very poor (umutindi), poor (umukene), well-off (umukene wifashije), rich (umukungu) and very rich (umukire). However, there is a short coming of the ubudehe system in that it cannot account for the income disparity across the different communities. For example, two households, one in an urban sector (*umurenge*) and the other in a rural sector (*umurenge*), could have exactly the same living conditions, but one could be classified as poor and the other classified as non-poor. This is because not all sectors have the same standard of living.

Each of the six categories is characterized by a number of criteria as follow:

►Vulnerable: They have to beg and have nothing; no clothes, no food, no medical care and have no farm land.

►Very poor: They do not have sufficient food but can work for others to survive; they dress poorly, have insufficient farmland and can hardly get medical care. They have shelter but no livestock and always suffering.

►Poor: They have small and poor shelter and a minimal harvest, their children can go to primary school, they can clothe themselves but with difficulty, they can hardly access medicare, but manage to have sufficient to eat and they have small ruminants.

►Well-off: They have excess harvest to sell and livestock, they can afford medicare and have a little money. Their children go to school. They eat well, are neat, have a good house and a bicycle,and can engage labour.

►Rich: They have excess harvest to sell and livestock, they can afford medicare and have a little money. Their children go to school. They eat well, are neat, have a good house and can engage other as labour.

►Very rich own a larger size of land, more livestock; sometimes have a job to generate money. Very rich: They have car, are running businesses in big cities.

### 1.5 Research questions

1. What are farmers' perceptions on soybean across different farm types? Are soybean production objectives and constraints the same among different farm types?
2. How does soybean perform relative to other major crops across different farm types, in terms of:
    a. Biological Nitrogen Fixation
    b. Contribution to soil fertility
    c. Contribution to household food self sufficiency
    d. Profitability
3. What are current market channels for soybean?
4. Where are potential niches for expansion of soybean production in Rwandese farming systems?

## 2 Materials and Methods

### 2.1 Site description

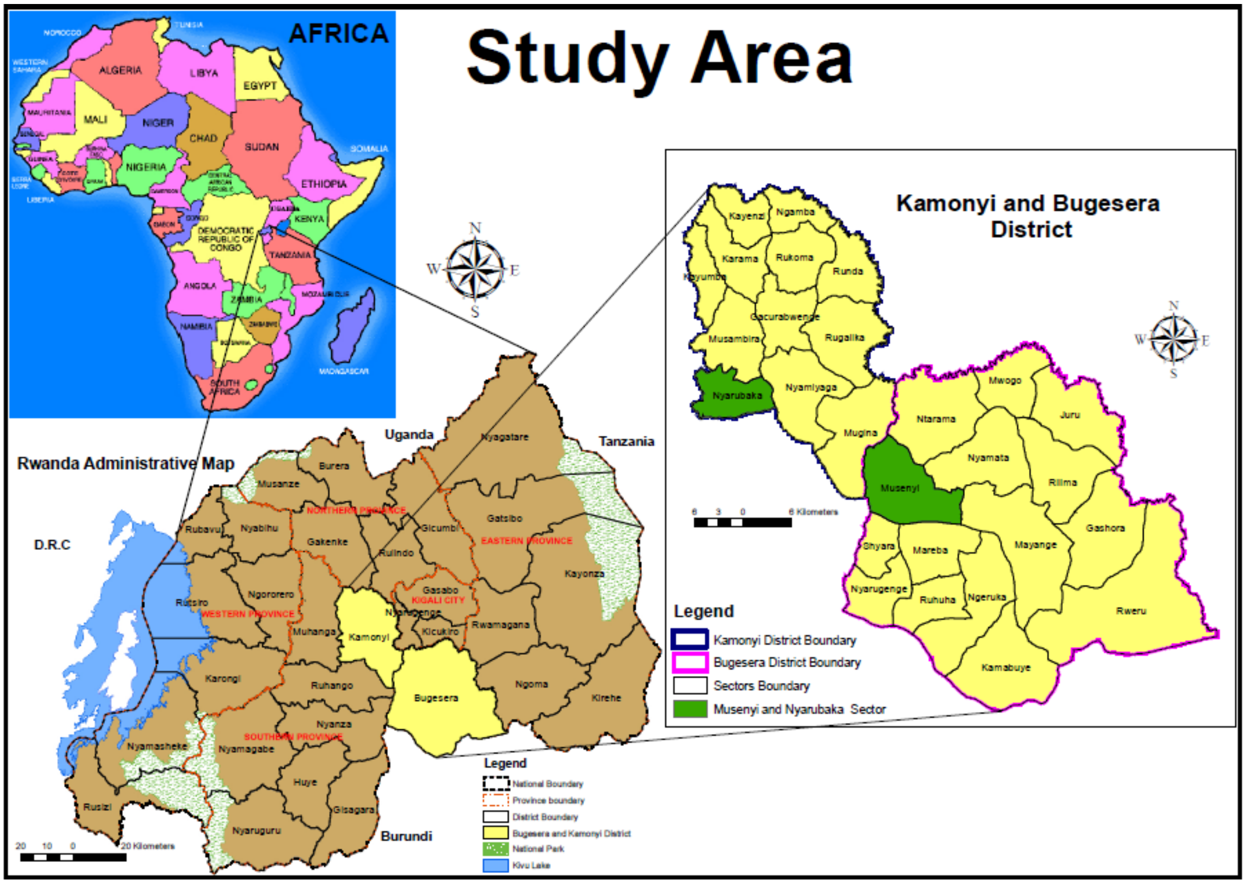



Fig. 2. Study sites

The research was conducted in two agro-ecological zones in Eastern and Southern Rwanda. Kamonyi district in the central plateau AEZ (1500-2000 m asl) and Bugesera district, Bugesera AEZ between 1300 m and 1667 m asl (Figure 2). Data were collected in the radius of 3.5 km around the village of Nyarubaka in Kamonyi and in radius of 5 km around the village centre of Musenyi in Bugesera. Bugesera is less populated than Kamonyi with population density of 194 and 339 person km$^{-2}$ respectively. Main markets for the outputs are Gacurabwenge, Muhanga and Kigali for Kamonyi while for Bugesera there are Nyamata, Ruhuha and Kigali. The access to urban markets in hours is similar for both regions. Mean annual rain fall is 1068 ± 49 for Kamonyi and 937 ± 42 in Bugesera. The annual mean temperature season is 20$^{0}$C in Kamonyi and 21$^{0}$ C in Bugesera. Length of growing period is short in Bugesera than in Kamonyi with 290 days and 315 days respectively. Important crops are similar in both regions (beans, cassava, and maize) except soybean which is mainly grown in Kamonyi.

Table 2 Main biophysical characteristics, socio-economic indicators and crop production of the research sites

| Variable | Unit | Kamonyi<br>02$^0$06' S 029$^0$48' E | Bugesera<br>02$^0$13' S 030$^0$03' E |
|---|---|---|---|
| *Biophysical characteristics* | | | |
| Altitude | m | 1805 | 1403 |
| Annual mean rain fall | mm | 1068 ± 49 | 937 ± 42 |
| Total annual temperature | $^0$C | 20 | 21 |
| Length of growing period | days | 315 | 290 |
| Topography | | Flat to undulating | Flat to undulating |
| Dominant soil type | | Humic soils | Xero-Karolisols |
| *Socio-economic indicators* | | | |
| Population density | Inhabitants/km$^2$ | 339 | 194 |
| Common farm size | Ha | 0.2-0.7 | 0.2-0.7 |
| Market access | Hours | 2.5 | 2.5 |
| *Crop production* | | | |
| Food crops | | Beans, cassava, banana, maize , soybean | Cassava, beans, sweet potatoes |
| Cash crops | | Coffee, cassava | Coffee, groundnuts |

Monograhie du District de Bugesera, 2006; Monograghie du District de Kamonyi, 2011; N2 Africa progress report, 2011; REMA (2009)

Musenyi and Nyarubaka sectors in Bugesera and Kamonyi districts respectively were chosen as case study sectors for two reasons: in Bugesera, among other sectors where N2Africa activities are taking place there are Mareba and Nyamata. Nyamata sector is closer to Kigali city and is not representative of most other parts of Bugesera, whereas in Mareba sector, soybean growers were fewer and it was difficult to find the desired sample size. In Kamonyi, other sectors were Musambira and Nyamiyaga. COCOF activities are mainly taking place in Musambira and many soybean growers in this sector are COCOF partners, it would not be wise to take those farmers as the sector is not representative of soybean production throughout Kamonyi. Musenyi and Nyarubaka were found to be more representative of the two districts.

Field work was conducted in 2012A growing season from November 2011 until February 2012. Growing season A was targeted because most farmers prefer to grow legumes during this season, especially in lowland and central plateau regions. But still farmers grow some legumes in season B as legumes can be grown twice a year.

## 2.2 Farm identification, selection and detailed farm characterization

### Farm identification

Farms were identified and selected based on Ubudehe programme. We had a meeting with village leaders in both cells to identify households that belong to different categories of Ubudehe using the available list. We established a list of those households and their locations as well. Thereafter, we performed a walking visit one by one to find soybeans growers for the 2012A growing season. Among soybean growers in each category, four farmers were randomly selected. This made in total 32 farmers belonging to four farm types with 16 farms in each study site.

In Bugesera, the ubudehe categories were slightly adjusted because two farm categories were closer in wealth and there was no distinction between them. After the farm selection, we proceeded with visiting farmer by farmer and explained the objective of the study for further detailed study.

Among six farm categories of Ubudehe typology, two were excluded for our study. These are the lowest category (vulnerable) and the upper category (very rich). This was due to the fact that vulnerable farmers have no farmland and very rich farmers were not found in the study area. Thus, the study was conducted on four farm categories very poor, poor, well-off and rich farm types. Case study households are presented in Figure 3. They are represented by codes with first letter B or K symbolising Bugesera and Kamonyi respectively and second letter (v=very poor, p=poor, w=well off and r= rich).

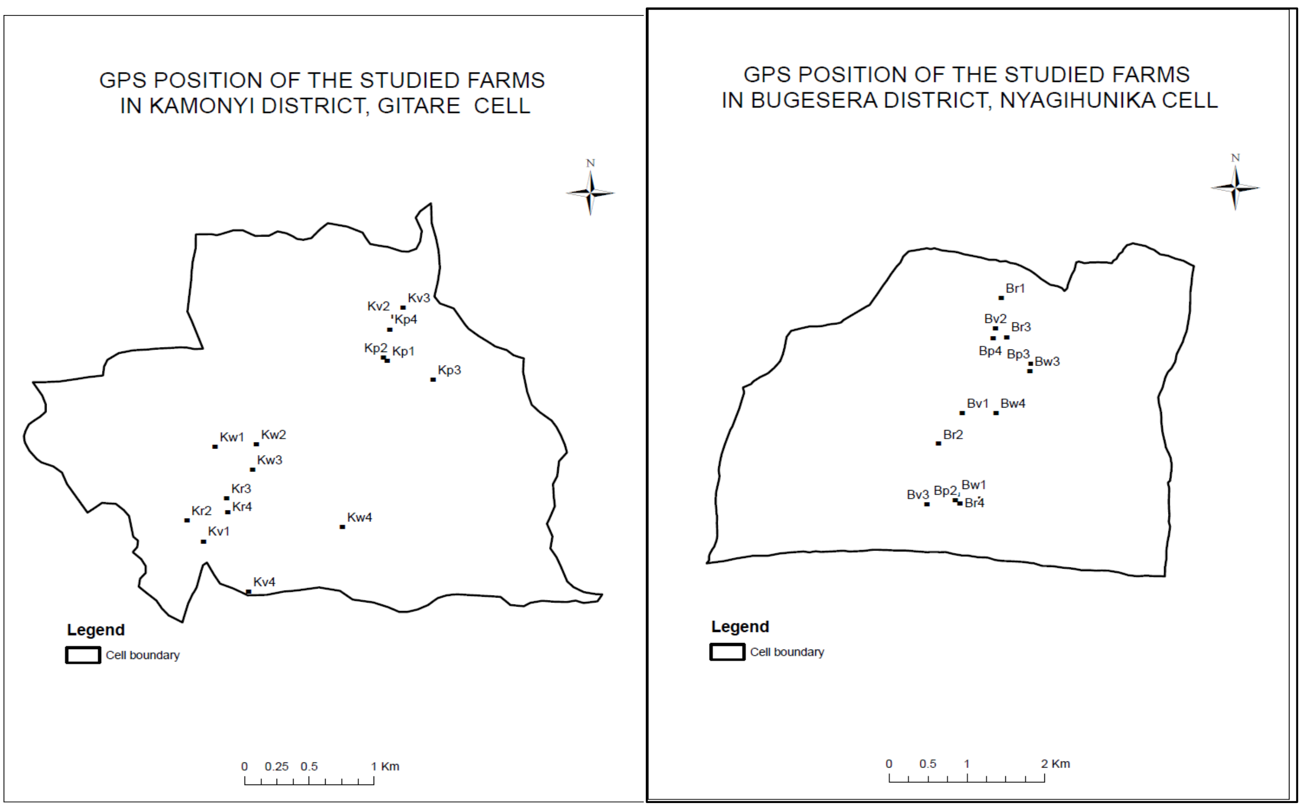



Fig. 3. Distribution of case study farms in Kamonyi and Bugesera.

**Detailed farm characterization**

Used approaches

After verification of farms categories using a rapid survey, detailed farm characterizations were conducted. To assess biophysical and socio-economic conditions related to legume production within each household, the following approaches were used. Field measurements were conducted to have the total farm size of each farmer and the land occupied by different crops, which provided information on important crops in each farm. A semi-structured interview was used to collect information on farm, field and crop management. Each household was visited four times during the growing season 2012A and the information received was crosschecked with wife or other household member during those visits**.** The characterization was time consuming in rich and well-off farm types as farms were complex and large while in poor and very poor the characterization was faster.

***Semi-structured interviews***

During the first visit, basic information about the village, household composition, cropping objectives and patterns were collected. Perceptions on legumes and soybean in particular were asked and soybean utilization within household. Questions about legumes and soybean expansion in particular, possibilities and constraints were also asked. In the second visit, all fields within the farm were measured and three of them were selected based on their location and crops grown to cover the diversity of fields within farm. Information about field management was collected including labor and input use, as well as residues management. In addition, visited farmers were asked to classify the fertility of fields, and basic information on slope, drainage and soil type was recorded. The third visit aimed to collect information on livestock, manure management, crop production activities and calendar. In a last visit, farmers were asked about their incomes and expenditures on farming as well as their yields variations for different crops.

***Farm visit, measurements and fields selection***

After taking GPS point of the homestead, together with farmer, we visited the farm. We measured all fields with a tape and GPS to get the exact size of the farm, except some that was not accessible given the distance between homestead and those fields. Fields situated on different slopes near, in the middle and far away from the homestead that had been cultivated with soybean, other legumes and staple crops were selected. Three fields were taken from each farm for detailed data collection on crop management, in total; ninety-six fields were selected. In those fields, soil samples, plant samples for biomass, grain and stover yields. Samples taken for grain and stover yields were prepared for N concentration analyses.

## 2.3 Biophysical measurements

### Soil sampling and analyses

In each of the selected fields, soil samples were randomly taken at a depth of 0-20 cm from ten spots. Using a soil auger sampler and following W in the field, a composite of sample of approximately 1 kg was taken. Prior to sampling at each field, an auger was first disinfected with 95% alcohol. Soil sampling was done in November, before legume flowering. Ninety-six samples were air-dried and sieved through 2mm in the National University of Rwanda laboratory and approximately 250 g of each sample was sent to Tropical Soil Biology and Fertility Institute (TSBF) laboratory in Nairobi for the analyses. The Crop Nutrition Laboratory Services in Nairobi (Kenya) analysed pH ($H_2O$), available P (Olsen), C.E.C, and exchangeable cations (K, Ca, Mg, and Na). The laboratory of the Tropical Soil Biology and Fertility Institute in Nairobi, prepared samples for organic carbon and total N analysis by fine grinding. Plant N concentration analysis, organic C and total N analyses were done in KU Leuven (Belgium).

### Quantifying soybean productivity trends relative to common bean

Common beans and soybean productivity was assessed through aboveground biomass harvesting and measurement of fresh and dry grain and stover yields. Measurement were taken at different development stages of crops following the stages of development of soybean developed by Fehr et al. (1971) (Appendix 3) which is applied to all soybean genotypes grown in any environment. Common beans measurements were taken following the stages developed by Van Schoonhoven and Pastor-Corrales (1987) (Appendix 4).

***Aboveground biomass assessment***

At mid podding of soybean and beans, biomass samples were taken from three locations in each field for determination of dry matter accumulation. As during farm visit, three fields were chosen and the purpose of selection explained to the farmers. A consensus was reached not to take leaves or fresh grain in the selected fields. In case the farmer had no other field he/she gave us a part of the field and he used the other part for fresh grain and leaves harvesting. Forty-two soybean above ground biomass samples and fifty-four bush beans above ground samples from ninety-six selected plots were collected. A representative sample was taken in three randomly areas of around 0.5 $m^2$ within plot avoiding borders. Fresh weigh were obtained immediately in the field after harvest using an electronic balance. All samples were packed in paper bags and labeled, then transported to National University of Rwanda (NUR) laboratory for oven drying at $70^0$C for 48 hours after which the dry weighs were recorded.

***Nodulation scoring***

After biomass sampling, six soybean and beans plants per field were sampled randomly. Nodules were scored based on a scoring scheme provided by Bala *et al*. (2010). Nodule number, size, distribution and active fixation were scored. The active fixation was indicated by a pink-red interior of nodule with medium to larger size. The effective nodules generally have pinkish red internal tissue, while ineffective nodules have green or white tissue Bala *et al*. (2010). Given that the number of nodules is higher for beans than soybean and the root system depths differ from one another, the scoring scheme was adapted for beans by increasing the number of nodules for each score.

Table 3 Scoring scheme for soybean and common bean nodulation assessment

| Legume | Soybean | | | | | | Common bean* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of estimated nodules | 0 | <5 | 5-10 | 11-20 | >20 | >50 | 0 | <10 | 10-20 | 20-30 | 30-50 | >50 |
| Score | 0 | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

*The same scheme was adjusted in case of beans nodulation scoring

With: 0= root nodules absent; 1= rare; 2= few; 3= moderate; 4=abundant and 5=super-nodulated

***Grain and stover yields measurement***

At maturity stage (near the end of growing season), grains and stover for both soybean and beans were harvested in about 1 $m^2$ in two locations from each field. Three stover and grain samples were taken from each farm. The above ground biomass was taken by cutting the plant at the ground level, grains were separated from stover and shed biomass was included in stover samples. Fresh weight was immediately measured on the field and sub samples were taken to NUR laboratory. All plant samples were oven dried at $70^0$C for 48 hours and dry matter was obtained.

### 2.4 N concentration and partial nutrient balances

***N concentration analyses***

Grains and stover samples from the final yield harvest were ground to pass a 1mm sieve in National University of Rwanda laboratory prior to N concentration analysis. A subsample of about 30 g for each sample was sent to Tropical Soil Biology and Fertility Institute (TSBF) laboratory in Nairobi (Kenya) for N concentration analysis. Legume grain and stover N concentration analyses were carried out in KU Leuven (Belgium).

***N export and net N from $N_2$-fixation***

The proportion of N derived from $N_2$-fixation (%Ndfa) was taken from literature. 45% and 32 % were considered as N derived from $N_2$- fixation for soybean and common bean respectively. N export in legume grain and stover was calculated based on N concentration and DM yields. Net N from $N_2$-fixation was obtained by subtracting N export from N fixed.

***Partial nutrient balances***

Partial N balance was calculated, taking into account organic and inorganic fertilizers applied and BNF as inputs. N concentration in dry yields of harvested grain and stover were taken as outputs. Additional inputs such as wet and dry atmospheric deposition were neglected as well as the additional losses through volatilisation, leaching, nitrification and denitrification. Nutrients content in cattle, goat/pig manure used by farmers were taken from literature; dung composts (with cow manure): 1.63%N; 0.18%P and 1.35%K (Drechsel and Reck, 1997) and dung composts (with goat/pig manure): 0.82%N; 0.17%P and 1.33%K (Drechsel and Reck, 1997). Nutrients content of chemical fertilizers used were taken from Bekunda and Manzi (2003) with DAP: 18%N and 20%P and urea: 46%N. The N output was calculated based on DM yields obtained and N content in plant from own data. Plant P and K content were calculated based on P and K concentration taken from Wortmann and Kaizzi (1998) and DM yields.

### 2.5 Nutritional Analysis

Protein and energy provision of soybean and other main food crops in Rwanda were calculated. Energy and protein content of different crops were obtained from FAO (1996) (Appendix 6). Energy and protein production by soybean and staples crops (kcal $ha^{-1}$) were computed and the total protein and energy production on the 1.5 year basis. Energy and protein production were calculated for beans, soybean, maize, groundnuts and cassava. Taking into account the growing period of cassava which is 1.5 year, for legumes and maize, energy and protein were tripled as these crops can be grown twice year. Food security status was assessed in terms of energy and protein availability within household and considering the number of consumers within each household. Adult humans require 2100 kcal/capita/day and 59 g of proteins according to Rwanda Ministry of Agriculture and Animal Resource. Children above 16 years were considered as adults, for children below 16 years the same amount of required energy for an adult person was counted for 2 children.

### 2.6 Economic Analysis

Economic analysis of soybean helps to understand its economic return to farmers and its contribution to household income generation relative to staple crops. The economic return was calculated using partial budgeting analyses to assess the contribution of soybean to farm income compared to staple crops (beans, cassava, groundnuts, maize and sorghum).

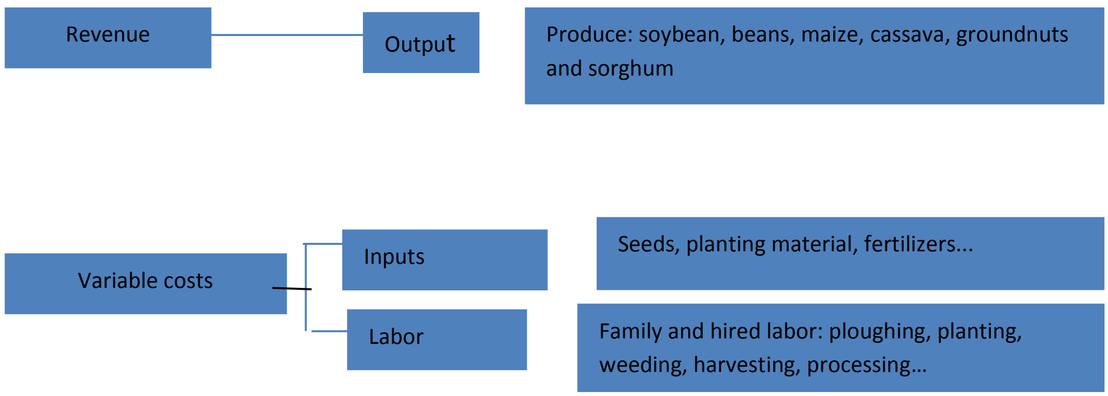



Fig. 4. Variables costs and output computation

Assuming that the produce consumed has the same value as the one sold to the market, the total yield was multiplied by unit price to get the output. Variables costs were computed considering the inputs used, as well as family and hired workers for different activities during cropping calendar. Output prices were average local markets prices during the two months following soybean and common bean harvest. The costs of crop production activities (ploughing (cost $ha^{-1}$), planting (cost $ha^{-1}$), weeding (cost $ha^{-1}$), harvesting (cost $ha^{-1}$), fertilizer application (cost $ha^{-1}$) were computed from the household survey data. Labour was valued at the local daily wage of 700 RWF (USD 1.15) in Bugesera and 800 RWF (USD 1.30) in Kamonyi per day (6 hours). The costs of inputs used (seeds, planting material, fertilizers) were determined from farmers and their local market price and the cost for each was converted into a per hectare basis. The farm gate price was also obtained from farmers while market prices were gathered on the nearby markets (Appendix 5). For legumes and maize, the return was tripled as these crops can be grown twice year and by taking into account the growing period of cassava which is 1.5 year.

To compare the benefits of technologies for soybean and major crops for household net return, simple economic analyses was carried out. The profit or marginal return (MNR) was computed for each crop as follow: MNR= Y*P-TVC (Ndakidemi, et al., 2006).

Where Y is yield of crop, P is selling price of crop at harvest (US\$ $kg^{-1}$), and TVC is the total variable cost of inputs related to the treatment (e.g. seeds, fertilizer, labour, etc. in (US\$ $ha^{-1}$)).

***Exploring scenarios in terms of economic and nutritional analyses***

Scenario 1: Traditional production

The presented scenario is the traditional mode of production. Fertilizer consists of compost and/ or animal manure used most of the time at a very low level compared to what research recommends. Less mineral fertilizer is also used in some farms. Seeds are mostly from farmers 'own production, sometimes bought from neighbors or from the local markets.

Scenario 2: Improved techniques

This scenario corresponds to the use of organic and inorganic fertilizers, improved seeds, inoculants and other improved cultivation techniques. Such scenario is almost inexistent on land area farmed by individual farmers.

A reference was made from N2Africa agronomic trials in different regions of Rwanda. Peka 6 soybean variety was tested in two sites; Kawangire (Kayonza) and Musambira (Kamonyi). The results from 2011 agronomic trials 2011 in both sites were averaged and used for calculations. Input trial using triple superphosphate combined with potassium chloride TSP/KCL and inoculum was chosen since soybean response seemed to be good for this input and its return to the cost of input was higher compared with other inputs used. Soybean yields obtained in control plots in both sites were averaged and these gave 1211 kg $ha^{-1}$. Also, grain yields obtained for TSP/KCL with inoculum were also averaged and gave 1901 kg $ha^{-1}$. From these, yield increasing factor was calculated by dividing yields from improved techniques with yield of control plot which gave 1.6. Each soybean yield in all farm types was multiplied by the yield increasing factor to obtain the yields in improved techniques. Based on N2Africa project recommendations in Rwanda, assumptions were made that all farmers used 0.8 kg $ha^{-1}$ of inoculants, 150 kg TSP $ha^{-1}$ and 60 kg KCL $ha^{-1}$. Inputs costs were considered as follow; seeds price was raised to 500 RWF (0.82 US$) assuming that farmers get certified seeds, 1 kg TSP and 1 kg KCL are purchased at 1 US$ each, a packet of inoculant 80 g (500 RWF = 0.82 US$) and the grain price was raised to 500 RWF (0.82 US$) $kg^{-1}$ which is the price for good quality soybean grains.

### 2.7 Market Surveys

To understand the link between soybean growers and market, we interacted with industry and local processors to understand what they want and with farmers to evaluate their ability to deliver grains that meet the industry and processors demand and specifications.

The main objective of the market surveys was to identify the important market channels and structure for soybean in the project mandate areas and to analyze each identified market level along the channel. This would enable identification of opportunities and constraints of soybean growers. A total of 4 market types comprising collectors and processors were surveyed using questionnaire interviews. The survey provided data about the quantity needed, preference, frequency of delivery and price were also gathered. These were basics in determining the size of the niche markets.

Using a questionnaire, the information on the demand, where they get soybean, the price and whether the supply meets their demand were collected. A visit to each organization was organized and performed by the author. The results from that survey and the author's observation were vital input to draw and analyse market channels.

### 2.8 Statistical Analysis

Statistical significance of the differences between farms of different strata for the various socio-economic and biophysical indicators was assessed by analysis of variance (ANOVA) using IBM SPSS statistics 19. An analysis of variance was conducted to determine the effects of farm types, effects of various factors and their interaction were compared by computing least square means. Significance of difference was evaluated at $P<0.05$. Data were analysed by farm type, by site, across farm types and across sites.

## 3 Results

*General remarks*

In Kamonyi farmers were familiar with soybean growing and usage. Among selected farmers, forty per cent had soybean in cooperatives in marshland and grew also their own soybean on hill fields. In Bugesera, among selected farmers, no farmer was participating in soybean growers cooperatives, only two farmers had participated in N2Africa project activities in the previous season. Plots cultivated by cooperatives and resulting yields were excluded in the analyses. We have noticed that farmers belonging to farm Types 3 and 4 are mostly the ones participating in cooperatives because they own plots in marshlands. It was clear that farm management in households where a man is the household head was mostly decided by men and crop management was mainly decided by men for cash crops and women for subsistence crops.

### 3.1 Farm typology and system characterization

The existing farm typology based on wealth from Ubudehe was verified and four farm types were used for this study (Table 4). Although the typology was the same for both locations, resource endowment was slightly different between the two study sites. Farmers in Kamonyi had more assets and owned more cows while in Bugesera most farmers owned small ruminants. Kamonyi farmers live in big and well built houses while in Bugesera they stay in small houses built from mud. Land holdings were similar in both locations, except for farm Type 4 in which Kamonyi farmers had larger land holdings than Bugesera farmers. Overall, households belonging to farm Types 2 and 3 were more in both locations and this is in line with national statistics throughout the country. The total number of households belonging to each of the farm types in each studied Cell is also presented in Table 4.

Table 4 Wealth indicators and characteristics of different case study farms in Bugesera and Kamonyi districts

| *a.Bugesera* | Wealth indicator | Farm Type 1 | Farm Type 2 | Farm Type 3 | Farm Type 4 |
|---|---|---|---|---|---|
| | Total number of households in Nyagihunika Cell | 238 HH | 886 HH | 523 HH | 51 HH |
| | House characteristics | Small mud made house | Small mud made house | Medium mud made house | More than one medium mud made houses |
| | Average farm size (ha) | 0.3 | 0.7 | 1 | 2.5 |
| | Livestock | No livestock | At least cares 1 cow and 2-4 small ruminants for others | Have about 1 cow and 2-4 small livestock | Have about 2 cows and 4-8 small livestock |
| | Hire/sale of labour | Sell labour | Sell occasionally labour | Hire labour for cropping | Hire labour for livestock and casual labour for cropping activities. |
| | Production orientation | Produce for basically home consumption | Produce for home consumption and can sell a small amount | Produce mainly for home consumption and some crops for sale | Grow some vegetables for sale, own coffee and banana plantations |
| | Income sources | Sales of labour like working in others farms, get some governmental help | Sales of few crop products and occasionally work for others | Rely on crop sales, banana and sorghum beer brewing | Have small scale businesses like banana beer brewing and occasionally jobs |
| | Food security | Buy food for periods of more than 6 months | Buy food for periods of 3-6 months | Buy food for periods of 1-3 months | Buy food for periods less than one month in a year |

| b.Kamonyi | Wealth indicator | Farm Type 1 | Farm Type 2 | Farm Type 3 | Farm Type 4 |
|---|---|---|---|---|---|
| | Total number of households in Gitare Cell | 178 HH | 803 HH | 347 HH | 69 HH |
| | House characteristics | Small and mud made house | Medium house | Big and cemented houses | Big and cemented house with metal doors and glasses windows |
| | Average farm size (ha) | 0.2 | 1.3 | 1.5 | 3.5 |
| | Livestock | goats cared for others | Have at most 1 cow cared for others | Have about 2 cows and 1 small livestock | Have about 4 cows and 4-6 small livestock |
| | Hire /sale of labour | Sell labour like working in others farms | Sell occasionally labour and sale a small amount of produce | Mainly hire labour for cropping activities | Hire labour for livestock and casual labour for cropping activities. |
| | Production orientation | Produce for basically home consumption | Produce for home consumption and can sale a small amount | Grow some vegetables, roots and grain crop specifically for sale, own medium coffee plantation | Grow some vegetables, roots and grain crop specifically for sale, own big coffee plantations |
| | Income sources | Work in others farm permanently | Occasionally work in others farm | Rely of crop sales and occasionally some small jobs | Have medium to small scale Business like shops and occasionally jobs; |
| | Food security | Buy food for periods of more than 6 months | Buy food for periods of 3-6 months | Buy food for periods of 1-3 months | Buy food for periods less than one month in a year |

### 3.1.1 Socio-economic characteristics

***General observation on socio-economic characteristics of case study farms***

Farm Type 1 consisted of very poor farms in which food insecurity occurs and one or more family members worked as casual labour on others farms in order to get income and food. A farm of this type was poorer in Bugesera than in Kamonyi. They start eating legumes even before the harvest time, first harvest fresh leaves and fresh grains which help them before crops are ready to be harvested.

Farm Type 2 was poor farms but they are less poor than Type 1. They are similar in both locations and most of them care for livestock of wealthier farmers. They are food secure but do not have surplus to sell except in some cases that they can sell a little of their produce. They are not able to hire labor and they rely on family labor but do not work as laborer in other farms except in fewer cases.

Farm Type 3 was well-off; had an off-farm employment around the village and they also earned income from selling surplus of their produce. Some of them generate money from sorghum and banana beer brewing.

Farm Type 4 had typically larger land holdings compared to other farm types and a large number of livestock. Generally, farm types 3 and 4 were able to hire labour and owned coffee plantations. They had job opportunities and their children were also active in generating income such as driving motor cycles and small businesses like shops in the village.

***Land ownership***

Major crops mentioned in different farm types, total land size, and land labour ratios are summarized in Table 5. Also, the relationship between average total farm size for each farm type and the land allocated to legumes and soybean in particular was obtained in Table 5. Land size was a main economic characteristic and in most cases the larger the land owned, the higher the farmer's resource endowment. In Kamonyi, farm Types 3 and 4 had relatively larger land sizes compared to Bugesera whereas the Type 1 has higher land size in Bugesera compared to Kamonyi. The land/labour ratios being dependent on the available labour within household and farm size, it depended on farm type and region. Land labour ratio was lower in farm Type 1 in Kamonyi while Types 2, 3 and 4 had a relatively higher ratio. In contrast to Bugesera, all farm types except Type 4 had a lower land/ labour ratio. This may be explained by two reasons; first, farmers in Kamonyi had larger land holdings compared to Bugesera. Second, in Bugesera there are Burundian people who came from neighbouring regions of Burundi. These people work in Bugesera and may increase the available labour.

Table 5 Main crops, average farm size, land/labour ratios and average land allocated to legumes across different farm types in both locations

| | | Main crops | Farm size (ha)[a] | Land/labour ratio (ha/person)[a] | Land under legumes (ha)[b] | Land under soybean (ha) |
|---|---|---|---|---|---|---|
| *Bugesera* | 1 | Common beans | 0.30(0.12) | 0.24(0.15) | 0.20 | 0.05 |
| | 2 | Common beans, groundnuts | 0.68(0.15) | 0.26(0.05) | 0.17 | 0.03 |
| | 3 | Beans, Cassava ,coffee | 0.99(0.03) | 0.25(0.03) | 0.32 | 0.10 |
| | 4 | Beans, Coffee plantations, banana | 2.25(0.58) | 0.50(0.08) | 0.84 | 0.05 |
| *Kamonyi* | 1 | Soybean, beans | 0.20(0.46) | 0.14(0.06) | 0.18 | 0.05 |
| | 2 | Beans, cassava, soya | 0.71(0.15) | 0.42(0.08) | 0.10 | 0.02 |
| | 3 | Coffee plantation, cassava, beans | 1.30(0.40) | 0.66(0.20) | 1.00 | 0.08 |
| | 4 | Coffee plantation, cassava, beans | 3.10(1.05) | 0.67(0.17) | 1.43 | 0.16 |

*[a]Values in brackets are standard error means*

*[b]Land under legumes includes land allocated to soybean*

In Bugesera, land area allocated to legumes increased with farm size while no clear pattern was observed between farm size and land size allocated to soybean. In Kamonyi, both land area allocated to legumes and soybean are farm size dependent and the larger farm, the larger area on which legumes and soybean are grown.

***Farmers' income***

Farmers get their income from different sources and the proportion from each depends on farm type. Total income and its distribution among different sources are presented in Table 6.

Table 6 Average yearly income (US$)* and the proportion of income sources (%) per farm types in both locations

| | *Bugesera (n=4)* | | | | *Kamonyi (n=4)* | | | |
|---|---|---|---|---|---|---|---|---|
| *Farm type* | Average total income(US$) | Livestock (%) | Crop sales (%) | Off-farm (%) | Average total income(US$) | Livestock (%) | Crop sales (%) | Off-farm (%) |
| 1 | 115 | 0 | 0 | 100 | 115 | 0 | 0 | 100 |
| 2 | 264 | 10 | 47 | 43 | 167 | 18 | 82 | 0 |
| 3 | 593 | 4 | 67 | 29 | 935 | 6 | 60 | 34 |
| 4 | 849 | 12 | 39 | 49 | 1147 | 16 | 54 | 30 |

**1US$=606 RWF*

Livestock generated income through milk and sales of small livestock. Milk selling contributed much to the income of Kamonyi farmers as it has higher price 200 RWF $L^{-1}$ (0.33 US$ $L^{-1}$) compared to Bugesera 150 RWF $L^{-1}$ (0.24US$ $L^{-1}$), because this is sold in the Gitarama city which was accessible by bike. Small livestock contributed a lot to income in Bugesera. In Kamonyi, all farmers of Types 3 and 4 own cows and they sell 50 per cent of the produced milk and in Bugesera, Types 3 and 4 mostly keep goats and they sell the off-springs of these livestock as income generation.

Among other sources of income, crop sales were the main source for farm Types 2, 3 and 4 at both locations. At both locations, some farmers of Types 3 and 4 made money from banana beer and sorghum beer and this could come to 200000 RWF =330 US$ $year^{-1}$. In addition, they sell crops and earn money from coffee plantations. Both income from beer brewing, selling crop and coffee were counted in crop sales income.

Job opportunities also played a role in resource rich farms. In Kamonyi, among farmers of Type 4, one was working in the hospital and another got seasonal jobs and had motor cycle for commercial transportation as business and in Type 3, two had shops in the village.

Based on these results, wealth indicators as farm size, off-farm income and assets explained most of the socio-economic variability among farmers. Ubudehe context is therefore effective in capturing the variability among smallholder farmers. However in Bugesera, assets did not explain the variability as farmers' houses were of the same standards and owning bikes was compulsory for all households irrespective of resource endowment due to regional dryness history and poor water availability to the people most owned bikes to facilitate water fetching.

### 3.1.2 Cropping system

#### ***Cropping history and crop rotation***

In Bugesera, common beans, soybeans, maize and groundnuts are cultivated in seasons A and B and sorghum only in season B. Farmers in Bugesera preferred growing beans in season B because they assumed to have enough rainfall by that time compared to season A. Typical crop rotation in Bugesera were beans-beans or beans-sorghum on hills and maize-potatoes in swamps. In case soybean was grown, it was grown in rotation with beans, in intercropping with cassava or in rotation with sorghum. The majority of fields allocated to soybean were preceded by beans. In Kamonyi, common beans are mainly cultivated in season A and to a lesser extent in season B. In marshlands, soybean is cultivated in season A, rotated with maize which is grown in season B. On hills, farmers cultivate soybean in both season A and B mostly intercropped with cassava. Sorghum is only cultivated in season B. Soybean was grown in rotation with maize in marshlands and on hills the rotation was sometimes done by sorghum or beans.

Expanding, decreasing and abandoned crops were ranked by farmers. In Bugesera, common beans are increasing because these are staple crop to almost all Rwandese. Cassava is more drought tolerant and also a staple food and has a higher yield per unit area. The increase in maize production is due to governmental land consolidation policy which is currently promoting monocropping of maize in swamps. Coffee and banana are being increased in production in Bugesera as they are seen as cash crops. Sweet potatoes are decreasing due to the decrease in planting material as they used to be grown in swamps which are now used for growing maize. A decrease in soybean production was explained by most farmers as drought sensitive crop, also lower preference in terms of consumption and lower market value were mentioned by farmers as reasons.

In Kamonyi, soybean production is increasing for two reasons. Farmers mentioned the main reason to be the use in food recipes. The second reason was the market availability because of the existence of transformation units of soybean in the region. Besides, the production was also stimulated by the existence of many non-governmental initiatives that are all targeting maize cultivation as main crop and soybean as rotational crop in most swamps of Kamonyi. Common beans and cassava are expanding as staples crops. The reason for maize was both governmental policy and non-governmental initiatives. Coffee, being a cash crop, is given a higher priority.

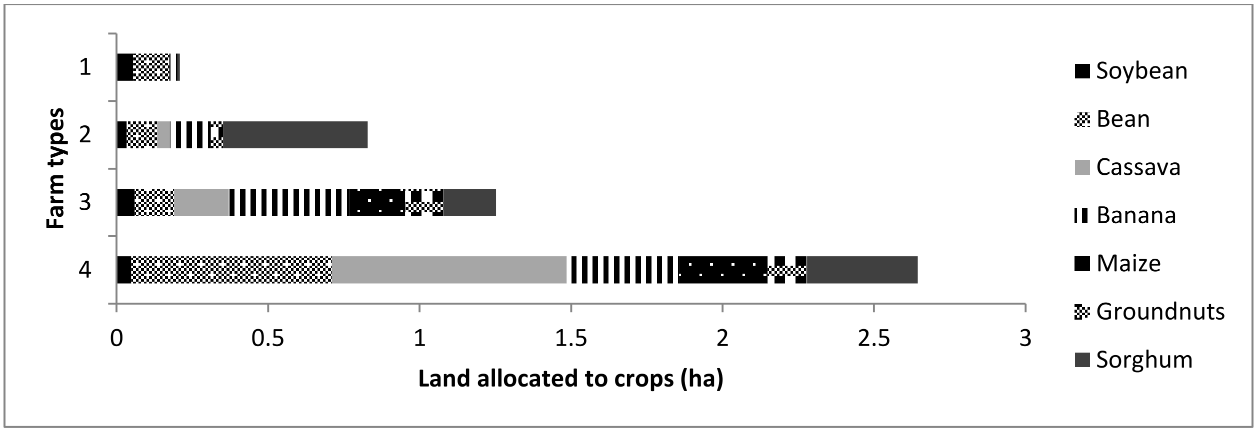
All farmers abandoned finger millet and cowpeas production because of low productivity and yields. Peas were abandoned due to susceptibility to pests and farmers said they cannot harvest any pea when they do not use pesticides and for farm Types 1 and 2 these inputs were too expensive. Moreover, the availability of pesticides in their localities was a challenge. Farmers' perceptions on crops increasing, decreasing and abandoned crops were gathered and summarised in Table 7.

Table 7 Crops with increasing, decreasing importance and abandoned crops

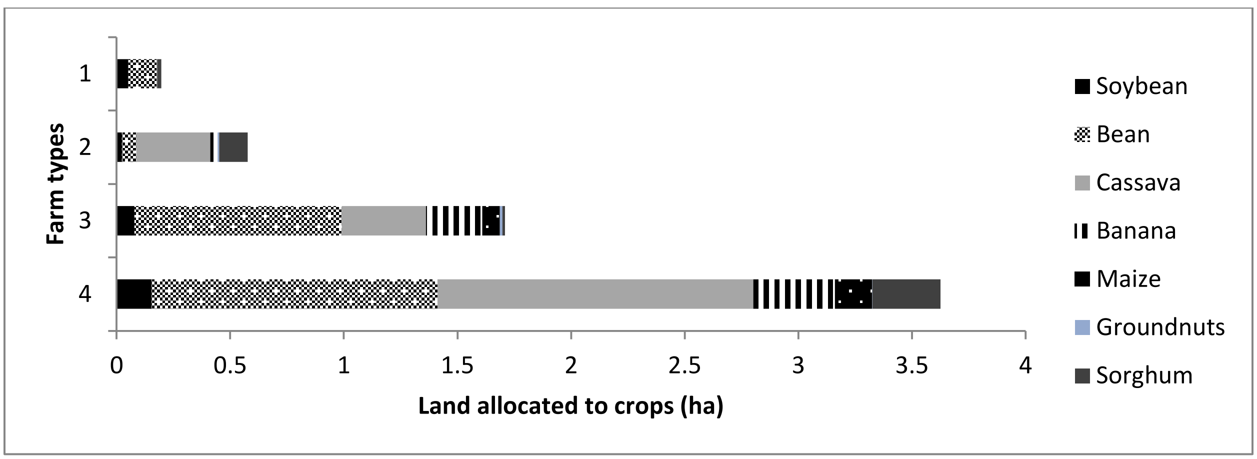
| location | Increasing | Decreasing | Abandoned |
|---|---|---|---|
| *Bugesera* | Common beans<br>Maize<br>Cassava<br>Coffee<br>Banana<br>Groundnuts | Sorghum<br>Sweet potatoes<br>Soybean | Cowpeas<br>Finger millet |
| *Kamonyi* | Cassava<br>Soybean<br>Common beans<br>Maize<br>Coffee | Sweet potatoes<br>Sorghum | Finger millet<br>Peas |

***Production patterns***

In both locations, common beans and cassava were staple crops. In Bugesera, common bean was the first occupying a large land followed by cassava, sorghum and banana, maize, groundnuts and lastly soybean grown at negligible area. In Kamonyi, common beans were also cultivated on very large land, followed by cassava; banana and sorghum came at a third place, then soybean and maize and lastly groundnuts. Although banana and cassava were grown for cash and food in Kamonyi, in Bugesera banana and sorghum were also used as crops generating income through beer brewing. Land allocation to different crops was farm type dependent and depended mostly on the production orientation, objective of the farmer and the importance given to them (Figure 6). For instance, banana and cassava are cultivated on larger fields; beans are also cultivated on larger fields and near homestead, while soybean is grown on small area of land and far from homestead. Resource poor farmers appeared to have less crop diversity at farm scale in general and more diversity of crops at field scale in both locations. In Kamonyi, none of the poor farmers grew banana and maize while in Bugesera no poor farmers grew maize and cassava. The reason may be that maize is grown in marshland and swamps and resource poor farmers do not have any plot there, also the small size of their land limit them to grow more crops.




a. Bugesera




b. Kamonyi

Fig. 5. Area of land allocated to selected crops across different farm types in Bugesera and Kamonyi. As most fields are intercropping, the percentage land cover of each crop was estimated and the area was calculated.

***Difference in land allocated to each crop across farm types***

In Bugesera, no significant differences in land area allocated to soybean cultivation across different farm types were observed. Farmers' crop ranking at both locations explained a big difference in land allocation to different crops at farm level. Beans were ranked as first main crop in almost all farm types followed by cassava. Specifically in Bugesera, sorghum and groundnuts were given higher rank compared to Kamonyi. Soybean was lastly ranked in many resource rich farms, and was mentioned a valuable crop only in resource poor farmers where soybean was consumed as soup and mostly milk and porridge for children.

Although there was no significant difference in total area of land allocated to soybean across farm types, soybean land share at farm level was higher in resource poor farms than in resource rich farms. For instance, in Bugesera 18 per cent of total land was used to grow soybean in farm Type 1 while 2 per cent of the total land was used to grow soybean in Type 4. The same was obtained in Kamonyi with 24 per cent of total arable land used to grow soybean in farm Type 1 whilst 5 percent were used in Type 4.

Farmers themselves explained the reason why they allocate differently the arable land to different crops in their households. Two case study farms are presented in the Figure 6.

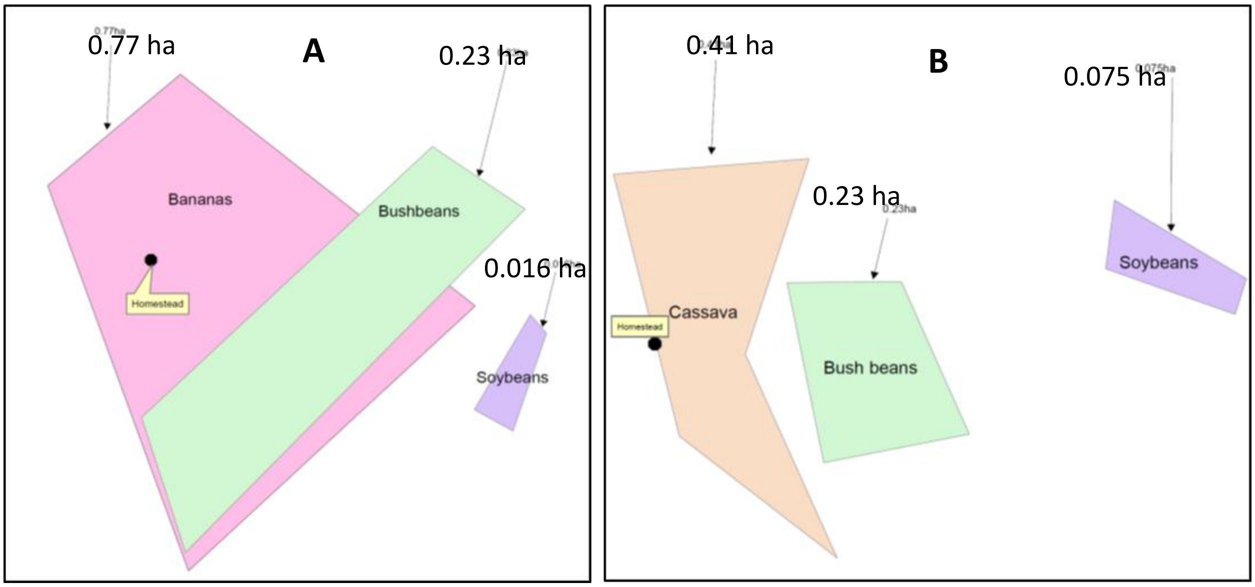



Fig. 6. Illustration of allocation of different crops in two of case study farms

In Figure 6, A is farmer Deo Kanyenzi, in Gitare cell, Kamonyi district. He belongs to farm Type 3 (a well-off farmer), grows banana on 80 per cent of his total farm and he applies cattle manure on banana because he harvest every three months banana and brews beer which constitute the main source of income to him. He also grows at larger extent common beans for his family. Soybean is cultivated at small area of land. Besides, beans are grown near homestead while soybean is grown far from the homestead.

B is farmer Fortunata Mujawamariya. She belongs to farm Type 4 (a rich farmer). For her, cassava is very important and is used for both cash and food security. She opted growing cassava for larger land and earns about 700 000 RWF= 1155 US$ per 1.5 year (1.5 year cassava growing period). Also she grows beans at a larger land area as she uses income from this in paying for hired labour during the planting season. Soybean is also an important crop to this farmer because it has higher market price compared to common beans but still the amount of land allocated to soybean is low.

***Labour use for different crops***

Groundnuts were the most labour intensive crop because of labour requirements for re-moulding. Approximately more than half of the labour was spent on the harvesting process which involved digging the belowground parts from the soil, separating nuts with haulms and mostly separation of seeds from the shells done by hands and took more time to do. Cassava seemed to be less labour demanding as most of labour used for weeding was counted in legumes production. Sorghum also was labour demanding crop because of extra work done during its growing period like covering shoots with more soil to protect them from falling down when windy. Farmers spent relatively small amount of labour on common beans and soybean because they are weeded only once and the grain separation from haulms is done by putting pods in sacks and beating them with a stick which is easily and quickly done.

Table 8 Average labour per crop per unit area across different farm types in both locations (Hours $ha^{-1}$)

| | Farm type | Soybean | Beans | Cassava | Maize | Groundnuts | Sorghum |
|---|---|---|---|---|---|---|---|
| *Bugesera* | 1 | 1035 | 2206 | NA | NA | NA | 3393 |
| | 2 | 1036 | 1623 | 1058 | 1964 | 1278 | 531 |
| | 3 | 1073 | 1486 | 491 | 1038 | 1807 | 1655 |
| | 4 | 1325 | 705 | 809 | 1086 | 1533 | 1347 |
| *Kamonyi* | 1 | 997 | 852 | NA | NA | NA | 536 |
| | 2 | 1677 | 1193 | 326 | NA | 1969 | 418 |
| | 3 | 857 | 498 | 1216 | 857 | 1031 | 1112 |
| | 4 | 1048 | 401 | 651 | 1048 | 2906 | 299 |

*NA= not available*

Higher labour input use observed in poor resource farmers for cassava, legumes and maize may be explained by the smaller field sizes and therefore lower use efficiency. Here we need to note that all labour input were farmer estimates and farmers often under or overestimate labour requirements because most farmers do not keep any record for cropping activities or the expenses for crops production. In general, farmers in Bugesera used more labour than in Kamonyi, which may be because of lower labour prices in Bugesera. However, at both locations, farm Type 3 and 4 seemed to use less labour for common beans production. Common cropping pattern is intercropping legumes with perennial crops such as cassava and banana which makes the evaluation of labour use efficiency of the system complex.

### 3.1.3 Animal husbandry

Farmers in Kamonyi kept more cows than in Bugesera but Bugesera farmers kept more small ruminants. The number of cows is farmer wealth dependent (Table 9). Farm Type 1 in Bugesera seemed to be the least in animal keeping. Farm Types 3 and 4 hire labour for animals keeping, looking for feed. They have pennisetum on field' borders and sometimes in fields but still, feeding animals is a problem because of zero grazing system. For small livestock, they can go outside for example grazing on the road side near the homestead. Other sources of feed are legumes and cereals crop residues and some farmers of farm Type 1 mentioned that they exchange their crop residues for manure with those keeping cows.

Table 9 Average number of cows and small livestock per farm type in both locations (n=4)

| | Farm type | Number of animal per farm(no) | | | | |
|---|---|---|---|---|---|---|
| | | Cows | Goats | Pigs | Sheep | Chicken |
| *Bugesera* | 1 | 0.0 | 0.3 | 0.0 | 0.0 | 1.0 |
| | 2 | 1.0 | 1.3 | 0.0 | 0.0 | 3.0 |
| | 3 | 1.0 | 7.0 | 1.0 | 2.0 | 0.0 |
| | 4 | 2.0 | 5.5 | 2.7 | 1.0 | 3.0 |
| *Kamonyi* | 1 | 0.0 | 0.0 | 1.0 | 0.0 | 1.0 |
| | 2 | 1.0 | 1.0 | 1.0 | 0.0 | 1.0 |
| | 3 | 2.0 | 3.0 | 0.0 | 1.0 | 2.0 |
| | 4 | 4.0 | 1.7 | 0.25 | 1.5 | 1.5 |

### 3.1.4 Inputs Use

***Inorganic fertilizers and biocides use***

Farmers used mineral fertilizers only for selected crops and this depended on farmer wealth and the priority given to the crop. Commonly used mineral fertilizers were NPK (17-17-17), DAP (Di-ammonium phosphate, 18-20.2-0) and urea. In both locations, NPK was used for coffee plantations and vegetables, such as cabbage, tomato and eggplant, because these are grown for income, farmers are willing to invest in them. Fewer farmers applied mineral fertilizer to soybean in Bugesera. Biocides are applied to coffee plantations and vegetables by few farmers.

***Organic fertilizer use***

The main organic fertilizer used in both locations is the composted animal manure. Table 10 summarises the application rate and nutrient content of animal manure, urea, and DAP used for different crops in Bugesera and Kamonyi. All quantities are estimates of farmers. Animal manure was used for different crops while mineral fertilizer was limited to specific crops, which highlight the importance of animal manure throughout different farm types. In Bugesera, farmers of Types 2, 3 and 4 used animal manure. In Kamonyi, in all farm types manure was used but with less number farmers of Types 1 and 2. The main source of manure was the livestock kept at homestead (owned or cared for others), mainly cattle in Kamonyi, and cattle and goats in Bugesera. Resource rich farmers applied more manure than resource poor farmers as the number of livestock was higher in wealthier than in poor farms. Nutrients (N, P and K ) applied to selected crops were calculated based on organic fertilizer application in different farm types, including cattle manure, composted goat/pig manure while inorganic were DAP and urea. The available manure for farmers is cattle manure and little from small animals. Those keeping only small animals have a very small amount of manure, because the production is higher for cattle than small livestock. Manure was collected and composted in heaps near the cattle housing and in both locations the heaps were not protected, except in few cases.

Table 10 Organic and inorganic fertilizers application rate (kg manure $ha^{-1}$) and nutrients (kg nutrients $ha^{-1}$)

| ***Organic*** | | Cassava | | | | Common bean | | | | Maize | | | | Soybean | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| farm type | | Application rate (kg $ha^{-1}$) | N | P | K | Application rate (kg $ha^{-1}$) | N | P | K | Application rate (kg $ha^{-1}$) | N | P | K | Application rate (kg $ha^{-1}$) | N | P | K |
| Bugesera | | | | | | | | | | | | | | | | | |
| | 1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 2 | 0.0 | 0.0 | 0.0 | 0.0 | 188 | 3.1 | 0.3 | 2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 3 | 150 | 2.5 | 0.3 | 2.0 | 895 | 12.2 | 1.6 | 12.0 | 321 | 5.2 | 0.6 | 4.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 4 | 75 | 1.2 | 0.1 | 1.0 | 2597 | 26.2 | 4.5 | 34.7 | 120 | 1.0 | 0.2 | 1.6 | 406 | 3.3 | 0.7 | 5.4 |
| Kamonyi | 1 | 0 | 0 | 0 | 0 | 786 | 17.1 | 1.9 | 14.1 | 0 | 0 | 0 | 0 | 986 | 21.4 | 2.4 | 17.8 |
| | 2 | 300 | 4.9 | 0.5 | 4.0 | 1975 | 32.2 | 3.5 | 26.6 | 0 | 0 | 0 | 0 | 2022 | 41.2 | 4.5 | 34.1 |
| | 3 | 435 | 7.1 | 0.8 | 5.8 | 1016 | 16.6 | 1.9 | 13.8 | 1287 | 21.0 | 2.3 | 17 | 2554 | 41.6 | 4.6 | 34.5 |
| | 4 | 530 | 8.6 | 0.9 | 7.1 | 1888 | 30.8 | 3.4 | 25.5 | 787 | 12.8 | 1.4 | 11 | 1845 | 30 | 3.3 | 24.9 |
| ***Inorganic*** | | | N | P | K | | N | P | K | | N | P | K | | N | P | K |
| Bugesera | | | | | | | | | | | | | | | | | |
| | 3 | | | | | | | | | | | | | | 2.0 | 2.2 | 0 |
| Kamonyi | 3 | | | | | | | | | | 35.2 | 10.9 | 0 | | 4.9 | 5.5 | 0 |
| | 4 | | | | | | | | | | 31.4 | 9.8 | 0 | | 4.4 | 4.9 | 0 |

*DAP: 18%N and 20%P (Bekunda and Manzi, 2003)*

*Urea: 46%N (Bekunda and Manzi, 2003)*

*Dung composts (with cow manure): 1.63%N; 0.18%P and 1.35%K (Drechsel and Reck, 1997)*

*Dung composts (with goat/pig manure): 0.82%N; 0.17%P and 1.33%K (Drechsel and Reck, 1997)*

## 3.2 Soybean production

### 3.2.1 Cultivation practices

Soybean is grown in most cases intercropped with cassava, common beans or other crops and in fewer cases monocropped. Planting season 2012A started a bit earlier due to rainfall availability in September after land preparation. It is normally weeded only once and the weeding took place earlier in December and farmers harvested it early February on hills and later February in marshlands. Farmers do not use any planting pattern and planting time ranged between end September and end-October. The difference in planting dates was due to the priority given to other cropping activities within household and this differed from one farmer to another and the availability of labour and input which also differed from a farmer to farmer. Resource-poor farmers started harvesting fresh grain in January and dry grains were harvested in February. The harvested grains were either kept for seeds and consumption or sold. Resource poor farmers sold grains after the harvest while wealthier farmers sold grains later when the prices were high.

### 3.2.2 Farmers' production objectives and perceived constraints

Soybean production objectives were not similar for both regions. In Bugesera, farmers mentioned household food production as the main objective. Income, soil fertility and casual labor were less mentioned. In Kamonyi, most farmers mentioned food and income as main objectives. Most of them like to increase the production for two reasons: nutritional value and market opportunity. Many transformation units are processing soybean around Kamonyi. Probably there is a transfer of knowledge and techniques for soybean processing and preparation from transformation units to the population around which motivates these farmers. Also the market opportunity provided by those transformation units stimulates soybean cultivation. Rotational and soil fertility improvement were less known to farmers while payment for casual labour was also mentioned particularly by resource rich farmers and low input demand was mentioned in only one farm (Table 11). Farmers liked to intercrop soybean with cassava, for them, intercropping is labour and land saving at the same time since they do not need labour to weed cassava.

Constraints were also farm type dependent (Table 11). Generally, the main constraint for resource poor farmers was land scarcity and financial means to purchase inputs. For resource rich farmers the main constraint was the availability of inputs such as chemical fertilizers and certified seeds in their localities. In Bugesera, the main constraints cited by farmers were drought and lower market price. Land scarcity was also mentioned but only in resource poor farms. In Kamonyi, labour was also mentioned in farm Types 1 and 2 as a main constraint, especially in widow headed households. In addition, resource poor farmers have to work for others in order to get seeds and other planting material. This causes them to delay planting on their own fields.

All farmers have the same understanding that soybean has to be cultivated where beans cannot grow well (marginal lands). Some Kamonyi farmers assumed that soybean may tolerate poor soils better compared to other crops. In Bugesera, farmers were not interested in soybean growing and explained that soybean is not preferred in terms of food and cash. Farmers said they prefer groundnuts instead of soybean because groundnuts have a higher price and its soup is more delicious than soybean. Besides, some farmers in this region believed that groundnuts are more tolerant to poor soils than soybean.

Table 11 Soybean production objectives and perceived constrains in different farm types. Number in brackets indicates the number of times that objectives or constrains were mentioned. In case reasons were mentioned with the same frequency, the reason which was prioritized by the largest number of farmers was put first.

| | Farm type | Production objectives | Main constraints |
|---|---|---|---|
| *Bugesera* | 1 | Food (4), soil fertility (1) | Drought (4),seeds availability (3), land (3) disease (2) |
| | 2 | Food (3) and soil fertility (1) | Drought (4), land (1), lower market price (3) |
| | 3 | Food (2) cash (2), Payment of casual labour (2) | Drought (3), lower market price (3) |
| | 4 | Payment of casual labour (2), food (2), cash (1) | Drought (4), lower market price (4), disease (2) |
| *Kamonyi* | 1 | Food (4), cash (1), soil fertility (2) | Land scarcity (4) labour (1), seeds cost (3) |
| | 2 | Food (4), cash (2), rotational effect (1), soil fertility (1) casual labour payment (1) | Labour (2), seeds cost (1), land (2) |
| | 3 | Food (3) cash (4) rotational effect (1), casual labour payment (1) | Land (3), input availability (1) lack of knowledge (2) |
| | 4 | Food (2) cash (4), soil fertility (2), casual labour payment (2) | Input availability (4), lack of knowledge (2) |

### 3.3 Soil fertility, crops productivity and N content

#### 3.3.1 Soil characteristics and fertility

***Soil fertility and farm types***

Bugesera soils had an average pH of 6.2 whereas Kamonyi soils had an average pH of 5.7. Soil pH levels were satisfactory in both locations ranging from 5.6 to 6.4. In Bugesera higher pH levels were observed in resource rich farms than resource poor farms. The reverse was observed in Kamonyi with slightly higher pH levels observed in resource poor farms. Total N and total organic carbon were high in Bugesera than Kamonyi for all farm types and in Bugesera higher levels were observed in resource rich farms than in resource poor farms. No pattern was observed in total N and organic total carbon across different farm types in Kamonyi. Available P was also satisfactory in both sites ranging from 28 ppm to 35 ppm in Kamonyi and from 21 ppm to 26 ppm in Bugesera, all above critical level of 10 ppm. Higher available P levels were observed in Kamonyi than Bugesera. A clear pattern in P levels across different farm types was observed in Bugesera with higher available P levels obtained in resource rich farms than in resource poor farms. No clear pattern was observed in available P across different farm types of Kamonyi. Exchangeable K, Ca and Mg levels were higher in Bugesera than in Kamonyi and a clear trend was observed in Bugesera where higher levels were obtained in resource rich farm than in resource poor farms. Total cation exchange capacity (CEC) was also higher in Bugesera (10 cmol kg$^{-1}$) than in Kamonyi (9 cmol kg$^{-1}$). Soils in Bugesera had higher clay content than soil in Kamonyi and Kamonyi soils had higher sand content compared with Bugesera. No clear pattern observed in clay and sand content of soils across different farm types in both sites.

Table 12 Average soil fertility parameters across different farm types at both locations

| | | n | pH | Olsen P(ppm) | C.E.C cmol kg$^{-1}$ | | | | | %N | %C | %Clay | %Sand | %Silt |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ($H_2O$) | | K | Ca | Mg | Na | C.E.C | | | | | |
| *Bugesera* | 1 | 12 | 5.8 | 20 | 0.91 | 2.10 | 0.84 | 0.10 | 9.39 | 0.12 | 1.32 | 42.9 | 49.3 | 7.8 |
| | 2 | 12 | 6.2 | 25 | 1.12 | 2.27 | 0.78 | 0.08 | 8.95 | 0.13 | 1.43 | 38.1 | 54.8 | 7.1 |
| | 3 | 12 | 6.4 | 25 | 1.06 | 3.08 | 1.01 | 0.11 | 10.89 | 0.14 | 1.56 | 41.5 | 49.0 | 9.5 |
| | 4 | 12 | 6.3 | 26 | 1.25 | 2.84 | 1.01 | 0.09 | 10.73 | 0.14 | 1.64 | 39.0 | 51.4 | 9.6 |
| *Kamonyi* | 1 | 8 | 5.8 | 33 | 0.60 | 1.80 | 0.65 | 0.13 | 7.82 | 0.09 | 0.92 | 26.5 | 63.0 | 10.5 |
| | 2 | 12 | 5.8 | 35 | 0.80 | 2.32 | 0.76 | 0.12 | 9.77 | 0.11 | 1.29 | 28.3 | 61.1 | 10.6 |
| | 3 | 11 | 5.6 | 28 | 0.45 | 1.69 | 0.49 | 0.12 | 7.42 | 0.09 | 1.09 | 30.7 | 61.1 | 8.2 |
| | 4 | 12 | 5.6 | 32 | 0.41 | 2.40 | 0.68 | 0.12 | 9.98 | 0.12 | 1.40 | 29.5 | 59.5 | 11.0 |

ANOVA was performed for pH, available P, exchangeable K, C.E.C, total N and organic carbon across different farm types and their means were compared based on the LSD multiple comparison test at 0.05 probability level. In Bugesera, a significant difference was observed in pH between farm type 1 and farm type 3 with

($p = 0.028$), and in total organic carbon between farm type 1 and farm type 4 with ($p = 0.047$). No significant difference was observed for other parameters. In Kamonyi, significant difference was observed for K between farm types 2 and 4 ($p=0.034$), for total N and total organic carbon between farm types 1 and 4 with (*p values* of 0.019 and 0.033) respectively.

***Soil fertility and crops***

In Bugesera, fields monocropped with soybean appeared to be less fertile with low levels of organic carbon, total N, available P and C.E.C. while in Kamonyi both fields monocropped with soybean and soybean intercropped with cassava were found to be less fertile with low levels of organic carbon, total N, available P, K and C.E.C. In these fields also pH levels were lower compared with other fields, with 5.9 for soybean monocrops in Bugesera, 5.5 for soybean monocrops in Kamonyi and 5.3 for soybean intercropped with cassava. Fields intercropped with common bean and banana seemed to be the most fertile in Bugesera with highest available P, K and C.E.C levels and relatively higher organic carbon and total N whereas fields monocroped with common bean were the most fertile in Kamonyi with highest available P, K, organic carbon, total N and C.E.C levels. Sole beans fields had low pH available P, K, Ca and Mg concentrations in Bugesera which was unexpected since most of them were near homestead. Most households put manure and ashes in near homestead fields providing base cations that can have an important liming effect. In both sites, fields intercropped with beans and cassavas were moderately fertile. In Bugesera, clay and soil particle size was quiet similar across fields of different crops while in Kamonyi higher clay content was observed in fields of sole beans and fields intercropped with beans and banana.

Table: 13 Average soil fertility parameters per crop at both locations

| | n | pH | Olsen P ppm | C.E.C cmol kg$^{-1}$ | | | | | %N | %C | %clay | %sand | %silt |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ($H_2O$) | | K | Ca | Mg | Na | C.E.C | | | | | |
| *Bugesera* | | | | | | | | | | | | | |
| Sole bean | 16 | 5.8 | 19 | 0.82 | 2.40 | 0.80 | 0.08 | 9.69 | 0.13 | 1.48 | 40.0 | 52.2 | 7.8 |
| Bean, Banana | 8 | 6.6 | 32 | 1.32 | 3.52 | 1.08 | 0.12 | 11.88 | 0.13 | 1.48 | 40.5 | 49.5 | 10.0 |
| Bean, Cassava | 7 | 6.1 | 23 | 1.04 | 2.41 | 0.93 | 0.08 | 9.61 | 0.14 | 1.61 | 40.8 | 49.7 | 9.5 |
| Sole soya | 8 | 5.9 | 23 | 1.2 | 1.6 | 0.75 | 0.11 | 8.01 | 0.10 | 1.27 | 41.2 | 51.8 | 7.0 |
| Soya, Cassava | 9 | 6.6 | 27 | 1.30 | 3.01 | 1.05 | 0.11 | 10.81 | 0.14 | 1.62 | 40.0 | 51.1 | 8.9 |
| *Kamonyi* | | | | | | | | | | | | | |
| Sole bean | 5 | 6.5 | 55 | 1.37 | 4.07 | 1.44 | 0.14 | 14.65 | 0.14 | 1.77 | 35.2 | 54.0 | 10.8 |
| Bean, Banana | 6 | 5.8 | 34 | 0.44 | 2.53 | 0.65 | 0.10 | 9.73 | 0.11 | 1.27 | 32.3 | 58.3 | 9.4 |
| Bean, Cassava | 11 | 5.8 | 33 | 0.61 | 2.26 | 0.67 | 0.11 | 8.91 | 0.10 | 1.27 | 28.0 | 61.8 | 10.2 |
| Sole soya | 12 | 5.5 | 26 | 0.38 | 1.47 | 0.47 | 0.14 | 7.34 | 0.96 | 1.05 | 27.2 | 62.8 | 10.0 |
| Soya, Cassava | 9 | 5.3 | 24 | 0.39 | 1.35 | 0.43 | 0.13 | 7.07 | 0.08 | 0.97 | 27.0 | 63.5 | 9.5 |

ANOVA was done for pH, available P, K, C.E.C, total N and organic carbon across fields with different crops and their means were compared based on the LSD multiple comparison test at 0.05 probability. Based on these, in Bugesera, for pH the significant differences were observed between fields under sole beans and fields intercropped with beans and banana (*p=0.002*), between fields monocropped with beans and fields intercropped with beans and cassava (*p=0.002*) and between fields under sole soybean and fields intercropped with soybean and cassava (*p=0.034*). For available P, the only significant difference was observed between fields monocropped with beans and fields intercropped with beans and banana (*p=0.032*). For K, a significant difference was observed between fields under sole beans and fields intercropped with beans and banana (*p=0.046*). For C.E.C, a significant difference was observed between fields with sole soybean and fields intercropped with beans and banana (*p= 0.020)*. For total N, the only significant difference was between fields under sole soybean and fields intercropped with soybean and cassava (*p= 0.035*).

In Kamonyi, for pH, significant difference was observed between fields under sole beans and fields intercropped with beans and cassava (*p= 0.044),* between fields under sole beans and fields under sole soybean (*p= 0.005),* and between fields under sole beans and fields intercropped with soybean and cassava (*p= 0.002).* For available P, significant difference were observed between fields under sole beans and fields intercropped with beans and banana (*p= 0.007),* between fields under sole beans and fields intercropped with beans and cassava (*p= 0.002),* between fields under sole beans and fields intercropped with soybean and cassava (*P< 0.001*) and finally between fields under sole beans and fields under sole soybean (*P< 0.001*). For K, significant difference was observed between fields under sole beans and all other fields (*p<0.001*). It was the same for C.E.C except between fields under sole beans and fields intercropped with beans and banana (*P=0.004*). For total N, fields under sole beans differed from fields intercropped with soybean and cassava (*p=0.004*) and from fields under sole soybeans (*p=0.016*) and finally for total organic carbon, fields under sole beans differed from fields intercropped with beans and cassava (p=0.041), from fields under sole soybeans (p= 0.004) and from fields intercropped with soybean and cassava (p= 0.002).

***Soil fertility and field distance from homestead***

Home fields seemed to be most fertile with higher levels for all soil fertility chemical indicators. Middle fields and outfields had closer levels of soil fertility parameters. pH was 6.3 in home fields while in middle and out fields pH was the same 5.7.

Field distance effect on soil fertility was statistically tested using ANOVA. A significant difference was obtained between home fields and outfields for almost all soil fertility parameters. The effect of field distance to soil fertility was also significant between home fields and middle fields except in exchangeable Na, total N and total C. There was no significant difference observed in soil fertility between middle fields and outfields (Table 14).

Table: 14 Average soil fertility parameters per field distance from homestead

| Field types | n | pH | Olsen P ppm | C.E.C cmol $kg^{-1}$ | | | | | %N | %C | %Clay | %Sand | %Silt |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $H_2O$ | | K | Ca | Mg | Na | C.E.C | | | | | |
| Home fields | 30 | 6.3 | 35 | 1.19 | 2.99 | 1.00 | 0.12 | 11.12 | 0.13 | 1.45 | 36 | 54.1 | 9.9 |
| Middle fields | 30 | 5.7 | 24 | 0.78 | 2.11 | 0.72 | 0.10 | 8.98 | 0.12 | 1.36 | 35 | 56.5 | 8.5 |
| Out fields | 31 | 5.7 | 25 | 0.58 | 1.95 | 0.64 | 0.11 | 8.32 | 0.11 | 1.20 | 34 | 56.8 | 9.2 |
| *P(0.05)* | | | | | | | | | | | | | |
| H&O[1] | | *0.001* | *0.007* | *0.000* | *0.001* | *0.000* | *0.422* | *0.001* | *0.035* | *0.013* | *NS* | *NS* | *NS* |
| H&M[2] | | *0.001* | *0.002* | *0.004* | *0.006* | *0.004* | *0.316* | *0.011* | *0.292* | *0.242* | *NS* | *NS* | *NS* |
| M&O[3] | | *0.952* | *0.706* | *0.155* | *0.627* | *0.401* | *0.834* | *0.420* | *0.287* | *0.180* | *NS* | *NS* | *NS* |

*[1] Between home fields and outfields*
*[2] Between home fields and middle fields*
*[3] Between middle fields and outfields*
*NS=not significant*

### 3.3.2 Productivity trends of soybean relative to other crops

***Crop dry grain and tuber yields***

Soybean and bean dry grains yields were measured while cassava tubers, maize and groundnut grains yields were estimated by farmers. For both locations, yields of crops were variable across farm types. Farm Type 1 of Bugesera obtained the lowest soybean yield. In general, common bean had higher dry grain yield compared with soybean. Soybean dry grain yield was higher than groundnuts in all farm types. A clear pattern was observed in cassava production where wealthier farmers obtained higher dry yields than poor farmers (Table 15). In Bugesera a clear pattern in common beans and soybeans production was observed across different farm types, with higher dry grain yields obtained in resource rich farms, Types 3 and 4 than in resource poor farms, Types 1 and 2. No clear pattern was observed in soybean and common beans dry grain yields in Kamonyi across different farm types. For all crops, yields were also variable within farm, with different plots generating different yields. Also, farmers estimated the yields in previous seasons and these yields varied a lot. Farmers estimates of lowest and highest obtained yields for period 2008-2011 seemed to be lower compared to measured yields of 2012, especially for common beans in Bugesera maybe because 2012A was a good season with enough rainfall. Although the accuracy in yields estimates by farmers may be questionable, still this gives a general picture of yields variations.

Table 15 Average measured soybean and bean dry grain yields, estimated cassava dry tubers, and maize and groundnuts dry grain yields for the 2011/2012 cropping season per farm type (kg ha$^{-1}$). Minimum and maximum yield estimates of farmers within a type are presented in brackets.

| *Bugesera* | Farm type | Soybean (kg ha$^{-1}$) | | Beans (kg ha$^{-1}$) | | Cassava (kg ha$^{-1}$) | | Shelled groundnuts (kg ha$^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|
| | | n | | n | | n | | n | |
| | 1 | 4 | 219 (148-334) | 8 | 612 (135-391) | | NA | | NA |
| | 2 | 4 | 554 | 8 | 729 (209-561) | 2 | 1087 | 2 | 338 (116-274) |
| | 3 | 4 | 596 (185-538) | 8 | 1004 (412-693) | 4 | 3486 (1570-3032) | 4 | 476 (265-558) |
| | 4 | 4 | 563 | 8 | 773 (405-637) | 4 | 4112 (1905-3761) | 3 | 469 (207-628) |
| *Kamonyi* | | | Soybean (kg ha$^{-1}$) | | Beans (kg ha$^{-1}$) | | Cassava (kg ha$^{-1}$) | | Maize (kg ha$^{-1}$) |
| | 1 | 4 | 546 (196-400) | 5 | 558 (125-440) | | NA | | NA |
| | 2 | 5 | 720 (299-590) | 5 | 892 (286-616) | 4 | 4723 (2117-4133) | | NA |
| | 3 | 4 | 802 (298-635) | 4 | 707 (352-726) | 4 | 6358 (3339-5958) | 4 | 965 (366-664) |
| | 4 | 4 | 687 (378-651) | 4 | 871 (462-902) | 4 | 5862 (3680-6053) | 4 | 1026 (394-665) |

*NA= not available*

***Measured above-ground biomass at mid podding and final stover yields for soybean and beans***

Generally, higher biomass was obtained in Bugesera than in Kamonyi for both common beans and soybean in all farm types except in farm Type 1. For both Bugesera and Kamonyi, there was a clear pattern in beans above-ground biomass across different farm types with higher biomass obtained in resource rich farms than in resource poor farms. No clear trend in soybean aboveground biomass across different farm types was observed (Table 16).

In Bugesera, common beans had higher stover yield than soybean in resource poor farms and the reverse was observed in resource rich farms. In Kamonyi, soybean had higher stover yield compared to common beans in all farm types. The highest soybean stover yield was obtained in farm Types 2 and 3 in Kamonyi and Types 3 and 4 in Bugesera (Table 16).

Table 16 Measured above-ground biomass at mid podding and final stover yield for soybean and beans across different farm types in both locations (kg $ha^{-1}$)

| | Bugesera | | | | | | Kamonyi | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| farm type | Beans | | | Soybean | | | Beans | | | Soybean | | |
| | n | Biomass | stover | n | Biomass | stover | n | Biomass | stover | n | Biomass | Stover |
| 1 | 8 | 1063 | 622 | 4 | 437 | 312 | 5 | 1273 | 453 | 4 | 1353 | 610 |
| 2 | 8 | 1694 | 1341 | 4 | 2400 | 531 | 5 | 1779 | 783 | 5 | 1371 | 892 |
| 3 | 8 | 2310 | 699 | 4 | 3279 | 757 | 4 | 2233 | 557 | 4 | 1214 | 1297 |
| 4 | 8 | 3064 | 620 | 4 | 2250 | 657 | 4 | 3425 | 594 | 4 | 1625 | 863 |

***Nodulation***

For both common bean and soybean, nodulation scores were higher in resource rich farms than in resource poor farms in both locations. Nodulation was poor in farm type 1 for both common bean and soybean in both locations

Table 17 Common bean and soybean nodulation scores across (0-5) across different farm types in both sites

| | Bugesera | | | | Kamonyi | | | |
|---|---|---|---|---|---|---|---|---|
| farm type | Beans | | Soybean | | Beans | | Soybean | |
| | n | score | n | score | n | score | n | score |
| 1 | 8 | 1.3 | 4 | 0.8 | 5 | 1.5 | 4 | 1.8 |
| 2 | 8 | 2.5 | 4 | 2.0 | 5 | 2.3 | 5 | 3.0 |
| 3 | 8 | 2.3 | 4 | 2.8 | 4 | 3.5 | 4 | 3.8 |
| 4 | 8 | 3.0 | 4 | 3.5 | 4 | 3.6 | 4 | 3.3 |

***N concentration***

Generally, higher N concentration was obtained in soybean grains than in common bean grains and the reverse was observed for stover N concentration in both locations. For soybean, higher N concentration was obtained in Kamonyi than in Bugesera. The proportion of N exported in grain was greater in soybean than in common bean in Kamonyi and less than common bean in Bugesera. In Bugesera, a clear pattern was observed for soybean grains N concentration where higher concentration were obtained in resource rich farms (farm types 3 and 4) than in resource poor farms (farm types 1 and 2) while for common bean higher grain N concentration was observed in resource poor farms. No clear pattern was observed in grain N concentration for both soybean and common beans in Kamonyi (Table 18).

Table 18 Average N concentration in grain and stover for soybean and common beans across farm types in both locations

| | | N concentration soybean (%) | | | | N concentration common bean (%) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Farm type | | n | Grain | n | Stover | n | Grain | n | Stover |
| Bugesera | 1 | 4 | 5.23 | 4 | 1.15 | 5 | 4.08 | 4 | 1.06 |
| | 2 | 4 | 5.14 | 5 | 0.66 | 6 | 3.99 | 6 | 1.17 |
| | 3 | 4 | 5.43 | 2 | 0.96 | 8 | 3.57 | 7 | 1.11 |
| | 4 | 4 | 6.43 | 4 | 0.82 | 7 | 3.38 | 7 | 1.34 |
| Average | | 16 | 5.6 | 15 | 0.89 | 26 | 3.75 | 24 | 1.17 |
| Kamonyi | 1 | 5 | 6.35 | 5 | 0.98 | 6 | 3.35 | 7 | 1.22 |
| | 2 | 4 | 6.35 | 5 | 0.84 | 7 | 3.37 | 5 | 1.29 |
| | 3 | 4 | 5.95 | 7 | 0.74 | 4 | 3.50 | 4 | 1.36 |
| | 4 | 6 | 6.18 | 4 | 0.91 | 4 | 3.51 | 4 | 1.53 |
| Average | | 19 | 6.21 | 21 | 0.86 | 21 | 3.43 | 20 | 1.35 |

### 3.3.3 N content and net N input from $N_2$-fixation

***N content in common bean and soybean***

N content in grain and stover was calculated based on N concentration and dry yields. In Bugesera, higher grain N content was obtained in common beans than in soybean in all farm types except in farm Type 4. The reverse was observed in Kamonyi, higher grain N content was observed in soybeans than in common beans in all farm types. Stover N content varied across sites; in Bugesera, higher stover N content was observed in common bean than in soybean. In Kamonyi, soybean had higher stover N content than common bean in farm Types 1 and 3. Nitrogen harvest index (NHI) ranged from 0.8 to 0.9 for soybean and from 0.7 to 0.8 for common beans (Table 19).

Table 19 N content in grain, stover and total N (kg $ha^{-1}$), and N harvest index for soybean and common beans across farm types in both sites

| Farm type | | N content in soybean | | | | | N content in common bean | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | n | Grain | Stover | Total N | NHI | n | Grain | Stover | Total N | NHI |
| *Bugesera* | 1 | 4 | 11.5 | 3.6 | 15.1 | 0.76 | 5 | 24.9 | 6.6 | 31.5 | 0.79 |
| | 2 | 4 | 28.5 | 3.5 | 32.0 | 0.89 | 6 | 29.1 | 15.7 | 44.7 | 0.65 |
| | 3 | 4 | 32.4 | 7.2 | 39.6 | 0.82 | 8 | 35.8 | 7.8 | 43.6 | 0.82 |
| | 4 | 4 | 36.2 | 5.4 | 41.6 | 0.87 | 7 | 26.1 | 8.3 | 34.4 | 0.76 |
| *Kamonyi* | 1 | 5 | 34.7 | 6.0 | 40.7 | 0.85 | 6 | 18.7 | 5.5 | 24.2 | 0.77 |
| | 2 | 4 | 45.7 | 7.5 | 53.2 | 0.86 | 7 | 30.0 | 10.1 | 40.2 | 0.75 |
| | 3 | 4 | 47.7 | 9.6 | 57.3 | 0.83 | 4 | 24.8 | 7.6 | 32.3 | 0.77 |
| | 4 | 4 | 42.4 | 7.9 | 50.3 | 0.84 | 4 | 30.6 | 9.1 | 39.7 | 0.77 |

***Legume N export and net N input from $N_2$-fixation***

The proportion of N derived from $N_2$-fixation (%Ndfa) was taken from literature. 45 per cent and 32 per cent were considered as N derived from $N_2$-fixation for uninoculated soybean and common bean respectively. In Bugesera, N fixed ranged from 7 to 19 kg N $ha^{-1}$ for soybean and from 10 to 14 for common bean. In Kamonyi, N fixed was (18-26 kg N $ha^{-1}$) for soybean and (8-13 kg N $ha^{-1}$) for common bean. A clear trend was observed in the amount of N fixed by soybean with relatively higher amount obtained in resource rich farms than in resource poor farms. No trend was observed in the amount of N fixed by common beans across different farm types (Table 20). Both soybean and common bean, N harvested in grains led to a negative net N input even if the stover was returned. When stover were removed from field, for soybean, negative net N input ranged from -8 to -23 kg N $ha^{-1}$ and from -22 to 32 kg N $ha^{-1}$ in Bugesera and Kamonyi respectively. For common bean, negative net N input ranged from -21 to -30 kg N $ha^{-1}$ and -17 to -27 kg N $ha^{-1}$ in Bugesera and Kamonyi respectively. N deficit was less when stover were to be returned to the field. For soybean, from -5 to -18 kg N $ha^{-1}$ and -16 to -22 kg N $ha^{-1}$ in Bugesera and Kamonyi respectively. For common bean, this ranged from -15 to -22 kg N $ha^{-1}$ and -11 to -18 kg N $ha^{-1}$ in Bugesera and Kamonyi respectively (Table 20).

Table 20 $N_2$- fixation, N accumulation, and net N input by soybean and common bean across different farm types in both locations

| Farm types | | n | Soybean Grain N[a] (kg ha$^{-1}$) | Soybean Stover N[b] (kg ha$^{-1}$) | Soybean Total N[c] (kg ha$^{-1}$) | Soybean N fixed[d] (kg ha$^{-1}$) | Soybean Net Input of N from $N_2$-fixation (kg ha$^{-1}$) (+) stover[e] | Soybean Net Input of N from $N_2$-fixation (kg ha$^{-1}$) (-) stover[f] | n | Common bean Grain N[a] (kg ha$^{-1}$) | Common bean StoverN[b] (kg ha$^{-1}$) | Common bean Total N[c] (kg ha$^{-1}$) | Common bean N fixed[d] (kg ha$^{-1}$) | Common bean Net Input of N from $N_2$-fixation (kg ha$^{-1}$) (+) stover[e] | Common bean Net Input of N from $N_2$-fixation (kg ha$^{-1}$) (-) stover[f] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Bugesera* | 1 | 4 | 11.5 | 3.6 | 15.1 | 6.8 | -4.7 | -8.3 | 5 | 24.9 | 6.6 | 31.5 | 10.1 | -14.8 | -21.4 |
| | 2 | 4 | 28.5 | 3.5 | 32.0 | 14.4 | -14.1 | -17.6 | 6 | 29.1 | 15.7 | 44.7 | 14.3 | -14.8 | -30.4 |
| | 3 | 4 | 32.4 | 7.2 | 39.6 | 17.8 | -14.6 | -21.8 | 8 | 35.8 | 7.8 | 43.6 | 14.0 | -21.8 | -29.6 |
| | 4 | 4 | 36.2 | 5.4 | 41.6 | 18.7 | -17.5 | -22.9 | 7 | 26.1 | 8.3 | 34.4 | 11.0 | -15.1 | -23.4 |
| *Kamonyi* | 1 | 5 | 34.7 | 6.0 | 40.7 | 18.3 | -16.4 | -22.4 | 6 | 18.7 | 5.5 | 24.2 | 7.7 | -11.0 | -16.5 |
| | 2 | 4 | 45.7 | 7.5 | 53.2 | 23.9 | -21.8 | -29.3 | 7 | 30.0 | 10.1 | 40.2 | 12.9 | -17.1 | -27.3 |
| | 3 | 4 | 47.7 | 9.6 | 57.3 | 25.8 | -21.9 | -31.5 | 4 | 24.8 | 7.6 | 32.3 | 10.3 | -14.5 | -22.0 |
| | 4 | 4 | 42.4 | 7.9 | 50.3 | 22.6 | -19.8 | -27.7 | 4 | 30.6 | 9.1 | 39.7 | 12.7 | -17.9 | -27.0 |

[a]*N export in grain*

[b]*N export in stover*

[c]*Total N export in aboveground dry matter*

[d]*N fixed is calculated based on 45 % N from $N_2$-fixation for soybean and 32 % from $N_2$-fixation for common bean (Nabahungu, 2012).*

[e]*Stover was to be returned to the field*

[f]*Stover was to be removed from the field*

### 3.3.4 Crop level partial N balances

Partial nutrient balances were calculated taking into account organic, inorganic fertilizers applied and BNF as inputs. N, P and K concentration in dry yields of harvested grain and stover were taken as outputs. Additional inputs such as wet and dry atmospheric deposition were neglected as well as the additional losses through volatilisation, leaching, nitrification and denitrification. Soybean and bean partial nutrients balances were calculated assuming first assuming that all crop residues are removed from fields and secondly assuming that crop residues are retained into fields.

***With all stover removed from the fields***

Most farmers tend to remove all crop residues from the field. Considering farmers practice; when all crop residues were removed; nutrient balances for soybean were negative in all farm types in Bugesera. For N ranging from -22 to -8 kg $ha^{-1}$, for P ranging from -3 to -1 kg $ha^{-1}$ and for K ranged from -12 to -5 kg $ha^{-1}$. In Kamonyi, soybean nutrient balances were positive except in farm type 1 where N and P were found negative. For N ranging from 12 to -1 kg $ha^{-1}$, for P ranging from 0 to 1 kg $ha^{-1}$ and for K ranged from 7 to 20 kg $ha^{-1}$. Negative balances obtained in Bugesera are explained by little use of fertilizer inputs in soybean fields while in Kamonyi almost all farmers applied manure in soybean fields (Fig. 7 A). Although soybean nutrients balance was positive in Kamonyi, the amount was still low, especially for N and P.

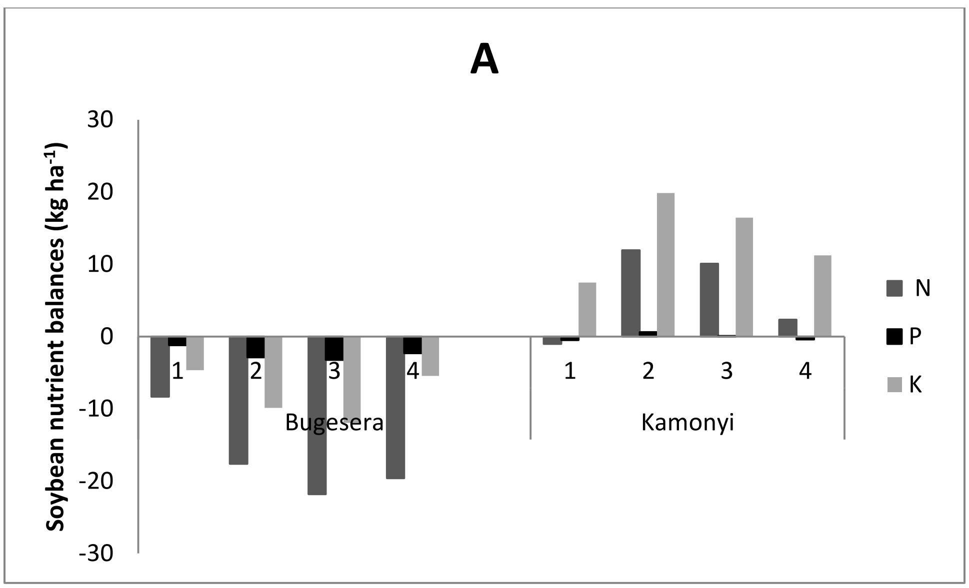



Fig. 7 A. Partial nutrient balances for soybean when all crop residues were removed from the fields

Bean partial nutrient balances were negative in all farm types of Bugesera, except in farm Type 4. Farmers of type 4 applied more manure in beans fields resulting in positive balances. In Kamonyi, bean partial nutrient balances were positive except in farm type 3 where N and P balances were negative. In Bugesera bean partial nutrient balances ranged from -27 to 3 kg $ha^{-1}$ for N, from -3 to 2 kg $ha^{-1}$ for P and from -16 to 21 kg $ha^{-1}$ for K. In Kamonyi, bean nutrient balances were -5 to 5 kg $ha^{-1}$ for N, -1 to 0 kg $ha^{-1}$ for P and 2 to 11 kg $ha^{-1}$for K (Fig. 7 B).

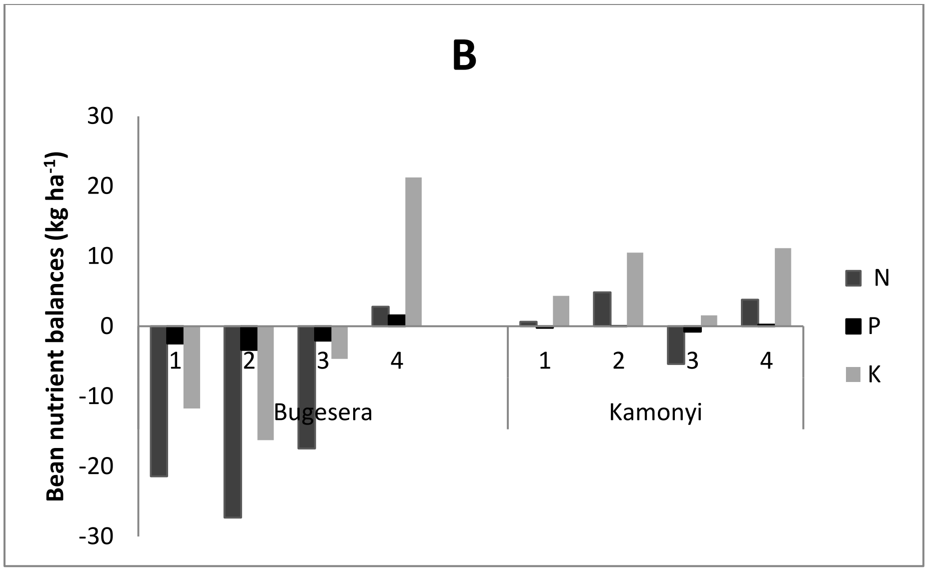



Fig. 7 B. Partial nutrient balances for beans when all crop residues were removed from fields

***With stover returned to the fields***

When stover were returned to the field, partial nutrient balances were improved in all farm types in both sites with higher positive impact in Kamonyi than in Bugesera. In Bugesera, nutrient balances for soybean remained negative in all farm types due to lower stover yield obtained in soybean in this region. In Kamonyi, N balances for soybean were positive in all farm types (Fig. 8 A). In Bugesera, soybean N balance ranged from -15 to -5 kg ha$^{-1}$, P balance from -3 to -1 kg ha$^{-1}$ and K balance from -7 to -1 kg ha$^{-1}$. In Kamonyi, N balance ranged from 5 to 20 kg ha$^{-1}$, P balance from 0 to 1 kg ha$^{-1}$ and K balance from 12 to 26 kg ha$^{-1}$. (Fig. 8 A).

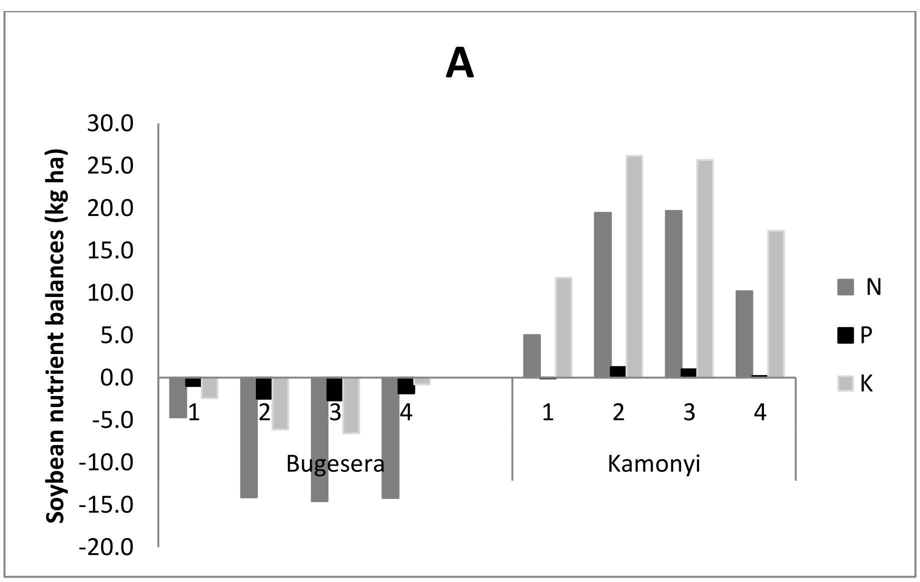



Fig. 8.A. Partial nutrient balance for soybean when all crop residues were returned to the fields

Bean partial nutrient balances were negatives in Bugesera except in farm Type 4. In Kamonyi, bean nutrient balances were positive in all farm types. Kamonyi farmers applied more manure than Bugesera farmers. In Bugesera, bean N balance ranged from -15 to 11 kg $ha^{-1}$, P balance from -1 to 2 kg $ha^{-1}$ and K balance from -7 to 26 kg $ha^{-1}$. In Kamonyi, N balance ranged from 2 to 15 kg $ha^{-1}$, P balance from 0 to 1 kg $ha^{-1}$ and K balance from 6 to 17 kg $ha^{-1}$. (Fig. 8 B).

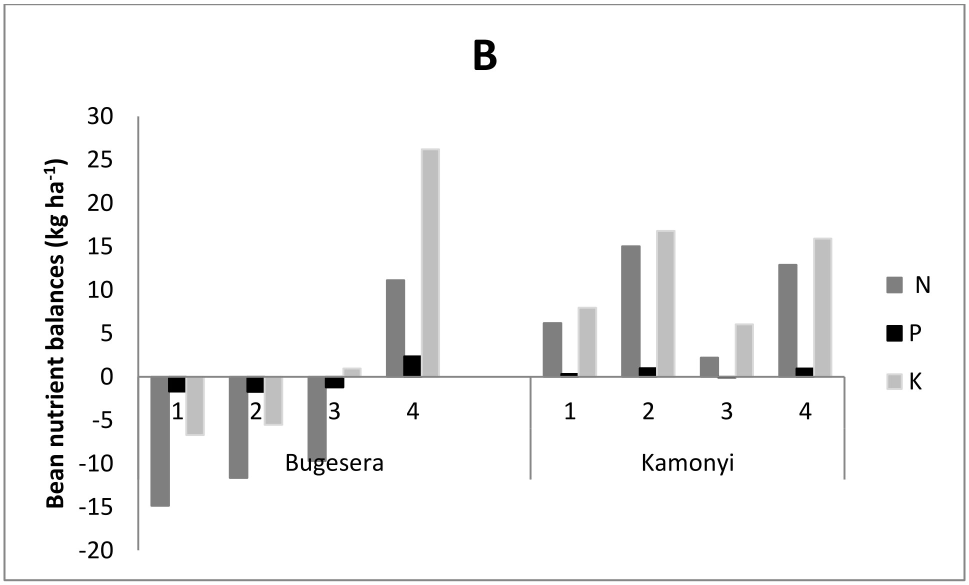



Fig. 8.B. Partial nutrient balance for beans when all crop residues were returned to the fields

## 3.4 Economic benefit of soybean relative to staple crops

Economic benefits were calculated for soybean and major food crops. Labour for cropping activities and seeds and other inputs used were counted as inputs. The outputs were obtained by multiplying crops produce by market prices. Average seeds and other purchased inputs prices, and commodity market prices are presented in (Appendix 5).

***Economic benefit of different crops per ha per farm type***

Taking into account 1.5 year as growing period of cassava, net returns for grain legumes and maize were tripled as they can be grown twice a year. Net return for sorghum was doubled. In Bugesera, groundnuts were the first in net return followed by cassava and beans, sorghum and soybean came last. In Kamonyi, groundnuts and cassava were the first followed by beans, then soybean and lastly maize and sorghum were the least. Soybean had a lower net return on the unit area basis compared to other crops in all farm types in Bugesera, but higher net return than maize in Kamonyi (Table 21).

Table 21 Net return of selected crops on ha basis (US$ $ha^{-1}$). Minimum and maximum returns are presented in brackets. Significant difference was calculated at P < 0.05

| Farm type | n | Common beans | n | Soybean | n | Cassava | n | Maize | n | Groundnuts | n | Sorghum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Bugesera* | n | | n | | n | | n | | n | | n | |
| 1 | 8 | -687(-1455; 453) | 4 | -371(-682; -94) | | NA | | NA | | NA | 2 | -602(-816; -386) |
| 2 | 8 | 129(-463; 584) | 4 | -6(-589; 234) | 2 | 214(-97; 739) | | NA | 2 | 567(552; 612) | 2 | 698(312; 994) |
| 3 | 8 | 481(253; 884) | 4 | 418(-281; 802) | 4 | 833(599; 1133) | 4 | 115(60; 187) | 4 | 990(-847; 1741) | 3 | 204(-830; 870) |
| 4 | 8 | 670(239; 1119) | 4 | -42(-349; 204) | 4 | 929(511; 1148) | 4 | 108(72; 139) | 3 | 1134(-74; 2210) | 4 | 264(118; 414) |
| *Kamonyi* | | | | | | | | | | | | |
| 1 | 5 | 14(-451; 212) | 4 | 115(-270; -539) | | NA | | NA | | NA | | NA |
| 2 | 5 | 331(-118; 731) | 5 | -93(-453; 269) | 4 | 1204(1040; 1334) | | NA | 2 | 1212(0; 121) | 2 | 338(0; 630) |
| 3 | 4 | 683(422; 982) | 4 | 602(-13; 1159) | 4 | 1435(1261; 1565) | 4 | 361(-62; 789) | 2 | 2768(2341; 3193) | | NA |
| 4 | 4 | 1150(868; 1495) | 4 | 492(-48; 963) | 4 | 1443(511; 1148) | 4 | 355(-92; 919) | 2 | 2389(2376; 2400) | 2 | 880(850; 908) |

*NA= not available*

In Bugesera, there was no statistically significant difference in net return from soybean (*p=0.076*) and groundnuts (*p=0.905*) across different farm types. A small difference was obtained in cassava (*p=0.06*), the significant difference between farm types was obtained in net return from beans (*p=0.019*), maize (*p=0.019*) and sorghum (*p=0.040*). In Kamonyi, no significant difference in net return was observed from soybean (*p=0.121*), and maize (*p=0.984*) between different farm types. A significant difference was obtained for the net return from cassava (*p=0.000*), beans (*p=0.001*), groundnuts (*p=0.013*) and sorghum (*p=0.045*).

***The implication of improved techniques scenario to household income***

The results of improved techniques scenario show positive soybean net returns in all farm types, except in farm Type 1 of Bugesera. In Kamonyi, this scenario gave higher soybean net return in all farm types compared to Bugesera with highest net return in resource rich farms than resource poor farms. Although, the net return of soybean increased in improved techniques, in Kamonyi, soybean net return remained low compared to groundnut in farm Types 3 and 4 and was low compared with cassava and groundnuts in farm Type 2. In Bugesera, soybean gave higher net return than other crops in farm Types 2 and 3, while in farm Type 4 net returns for cassava and beans were higher than soybean.

Table 22 Soybean net returns in improved techniques relative to net return of major crops in current production on ha basis ($ ha$^{-1}$)

| Farm type | | Common beans | Soybean | Cassava | Maize | Groundnuts | Sorghum |
|---|---|---|---|---|---|---|---|
| *Bugesera* | 1 | -687 | -702 | NA | NA | NA | -602 |
| | 2 | 129 | 834 | 214 | NA | 567 | 698 |
| | 3 | 481 | 1423 | 833 | 115 | 990 | 204 |
| | 4 | 670 | 634 | 929 | 108 | 1134 | 264 |
| *Kamonyi* | 1 | 14 | 703 | NA | NA | NA | NA |
| | 2 | 331 | 564 | 1204 | NA | 1212 | 338 |
| | 3 | 683 | 1926 | 1435 | 361 | 2768 | NA |
| | 4 | 1150 | 1516 | 1443 | 355 | 2389 | 880 |

### 3.5 Nutritional benefit of soybean relative to staple crops

***Energy and protein return on land per ha***

Crop energy and protein production per hectare were calculated based on crop dry matter yield an energy and protein content of each crop. Energy and protein content of different crops are presented in Appendix 6. Taking into account 1.5 year as growing period of cassava, the energy and protein for grain legumes and maize were tripled as they can be grown twice a year (Table 23). In general, cassava was the first in energy production in both locations. Beans were the second in Bugesera and maize was the second in Kamonyi and soybean came third in both locations. Groundnuts and beans came last in Bugesera and Kamonyi respectively. In Bugesera higher energy production per hectare was observed in resource rich farms than in resource poor farms for all crops. In Kamonyi, there was no clear pattern in energy production on unit area basis between farm types except for cassava where higher energy production was observed in farm Types 3 and 4 than Type 2. Energy yields were lower in Bugesera than in Kamonyi. In terms of protein yield, in Bugesera, common bean and soybean had almost similar yields except in farm Type 1. Groundnuts and cassava came last. In Kamonyi, Soybean was the first in protein production followed by common beans, maize and lastly cassava (Table 23). Soybean protein production was higher in Kamonyi compared to Bugesera and this was due to the lower yield of soybean in Bugesera. In Kamonyi, soybean produced higher protein in farm Types 2 and 3 compared to Types 1 and 4.

Table 23 Energy and protein yields return on land across different farm type in both locations

| Farm type | | Energy yield ($10^4$ kcal ha$^{-1}$) | | | | | | | | Protein yield (kg ha$^{-1}$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Beans | | Soybeans | | Cassava | | Groundnuts | | Beans | | Soybeans | | Cassava | | Groundnuts | |
| | | n | | n | | n | | n | | n | | n | | n | | n | |
| Bugesera | 1 | 8 | 617 | 4 | 267 | | NA | | NA | 8 | 422 | 4 | 222 | | NA | | NA |
| | 2 | 8 | 735 | 4 | 674 | 2 | 444 | 2 | 279 | 8 | 503 | 4 | 561 | 2 | 20 | 2 | 118 |
| | 3 | 8 | 1012 | 4 | 724 | 4 | 1185 | 4 | 784 | 8 | 693 | 4 | 603 | 4 | 52 | 4 | 331 |
| | 4 | 8 | 779 | 4 | 684 | 4 | 1398 | 3 | 580 | 8 | 533 | 4 | 569 | 4 | 62 | 3 | 245 |
| | | Beans | | Soybeans | | Cassava | | Maize | | Beans | | Soybeans | | Cassava | | Maize | |
| Kamonyi | | n | | n | | n | | n | | n | | n | | n | | n | |
| | 1 | 5 | 586 | 4 | 664 | | NA | | NA | 5 | 401 | 4 | 552 | | NA | | NA |
| | 2 | 5 | 903 | 5 | 875 | 4 | 1606 | | NA | 5 | 618 | 5 | 728 | 4 | 71 | | NA |
| | 3 | 4 | 713 | 5 | 975 | 4 | 2162 | 4 | 1034 | 4 | 448 | 5 | 811 | 4 | 95 | 4 | 272 |
| | 4 | 4 | 962 | 4 | 835 | 4 | 1993 | 4 | 1099 | 4 | 658 | 4 | 695 | 4 | 88 | 4 | 290 |

*NA= not available*

***Total energy and protein production on 1.5 year basis per farm type***

Total energy and protein production were calculated based on the total crop produce available in household. Calculations were made for a period of 1.5 year taking into account the growing period of cassava as a perennial crop. Energy and protein for legumes and maize were tripled since they can be grown twice a year. In both study sites, cassava was the first in total energy provision at household level, followed by common beans. Maize and groundnuts came third, and soybean at last place (Table 24). Cassava and common beans are grown on a larger area of land in both Bugesera and Kamonyi and their harvest are higher compared to other crops within household, their higher total energy production. For all crops, a clear pattern of total energy production was noticed between different farm types the energy production increased with farm wealth. This is due to the fact that, the more farm wealth, the more land and the more crop harvests.

Total protein production was higher for beans than any other crops followed by groundnuts in Bugesera and cassava in Kamonyi. Soybean came at third place in both locations and cassava and maize were the last in Bugesera and Kamonyi respectively (Table 24). Reasons are diverse, beans came first because they are cultivated over area land and their protein content is higher. Soybean has higher protein content but was cultivated over a small area, while cassava was cultivated on large scale but its protein content is very low. A clear trend was observed in protein production for all crops with higher protein production in wealthier farms than in poor farms. Generally, farmers in Kamonyi had higher total protein production than farmers in Bugesera.

Table 24 Total energy ($10^4$ kcal) and protein (kg) production per farm type per 1.5 year. Minimum and maximum energy are presented in brackets

| | Energy ($10^4$ Kcal) | | | | Protein (Kg) | | | |
|---|---|---|---|---|---|---|---|---|
| Bugesera | | | | | | | | |
| Farm type | Soybean | Bean | Cassava | Groundnuts | Soybean | Bean | Cassava | Groundnuts |
| 1 | 28(3.7-84) | 80(25-176) | NA | NA | 24(3-70) | 55(17-121) | NA | NA |
| 2 | 25(11-34) | 83(64-129) | 32(0-50) | 37(11-51) | 21(9-28) | 57(44-88) | 1 (0-2.2) | 15(5-21) |
| 3 | 49(7.2-108) | 122(97-149) | 215(115-341) | 99(36-181) | 40(6-90) | 83(67-102) | 10(5 -15) | 42(15-77) |
| 4 | 38(5.5-51) | 111(58-196) | 1087(621-1000) | 92(20-149) | 31(5-42) | 76 (40-135) | 48 (27-64) | 39(9-62) |
| Kamonyi | | | | | | | | |
| Farm type | Soybean | Bean | Cassava | Maize | Soybean | Bean | Cassava | Maize |
| 1 | 32(26-49) | 38(17-83) | NA | NA | 27(21-40) | 26(12-57) | NA | NA |
| 2 | 26(3.7-55) | 62(49-76) | 506(118-879) | NA | 22(3-45) | 43(34-52) | 22(8-39) | NA |
| 3 | 79(59-98) | 128(51-245) | 711(27-1000) | 77(57-105) | 66(50-81) | 87(35-168) | 31(1-63) | 20(15-28) |
| 4 | 148(28-405) | 122(35-230) | 2891(739-6000) | 170(42-440) | 123(23-34) | 84(24-157) | 128(33-261) | 45(11-116) |

***The implication of improved techniques scenario to household food security***

Improved techniques scenario increased both energy and protein production of soybean in all farm types compared to current production system. However, total soybean contribution to energy availability at farm level remained low when compared with major crops due to little land allocated to the crop production. But soybean contribution to protein was higher than any other crop except beans.

Table 25 energy and protein production of soybean improved techniques relative to energy and protein production of major crops in current production

| | Farm type | Energy ($10^4$ Kcal) | | | | Protein (kg) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Soybean | Bean | Cassava | Groundnuts | Soybean | Bean | Cassava | Groundnuts |
| Bugesera | 1 | 45 | 53 | NA | NA | 13 | 37 | NA | NA |
| | 2 | 40 | 63 | 32 | 37 | 11 | 43 | 1 | 15 |
| | 3 | 78 | 94 | 215 | 99 | 22 | 65 | 10 | 42 |
| | 4 | 60 | 474 | 1087 | 92 | 17 | 324 | 48 | 39 |
| | | Soybean | Bean | Cassava | Maize | Soybean | Bean | Cassava | Maize |
| Kamonyi | 1 | 51 | 48 | NA | NA | 14 | 33 | NA | NA |
| | 2 | 42 | 41 | 506 | NA | 12 | 28 | 22 | NA |
| | 3 | 126 | 415 | 711 | 77 | 35 | 284 | 31 | 20 |
| | 4 | 238 | 778 | 2891 | 170 | 66 | 532 | 128 | 45 |

***Food security status in studied households***

Food insecurity was observed in resource poor farms and more in Bugesera than Kamonyi.

Table 26 Food security in terms of energy and protein availability within studied households

| | Farm type | Energy diary per capita consumption (Kcal day $^{-1}$) | Protein diary per capita consumption(g day $^{-1}$) |
|---|---|---|---|
| *Bugesera* | 1 | 878* | 47* |
| | 2 | 1182* | 56* |
| | 3 | 3361 | 109 |
| | 4 | 10639 | 267 |
| *Kamonyi* | 1 | 1372* | 73 |
| | 2 | 7228 | 94 |
| | 3 | 9436 | 297 |
| | 4 | 17871 | 390 |

**Are not food secure*

## 3.7 Market opportunities

In this section, market channels are drawn and demand and supply are analysed.

### 3.7.1 Demand analysis

***SOSOMA Industries ltd***

SOSOMA Industries Ltd is a company which mainly deals with flour production and marketing activities. Among meal products are soya flour, maize flour, sorghum flour, SOSOMA 1, SOSOMA 2, fortified SOSOMA and others. To make these products, the company needs to purchase raw material such as soybeans, grain maize and grain sorghum. The company purchases 300 tons of soybeans a month of which a larger amount of soybean 220 tons is imported from regional market; Uganda through Gatuna and Kagitumba border posts which lie in the North and North east boundaries of Rwanda. Only 80 tons are locally sourced. These figures show the growth of soybean market in Rwanda and one can say that the local supply of soybean does not meet the demand.

***COCOF (Women Consultative Council)***

COCOF is a non-governmental initiative that involve local population especially women are trained on cultivation and small scale processing of soybean. The initiative delivers extensions services to the local population (COCOF beneficiaries) in terms of soybean cultivation and has a soybean production unit.

Production unit of COCOF transforms soybeans into various consumable products such as soya flour, composite flour made of soybean, maize and sorghum, fortified flour, soy meat (*TOFU*) and soymilk. These products are sold to the nearby town, Gitarama and to Kigali as well as to local people. To make these products, the transformation unit needs raw materials which are soybeans, maize, and sorghum. Hence, the unit provides the market not only for COCOF beneficiaries but also for local individual farmers within and nearby Kamonyi district. For example by the end of year 2009, transformation unit purchased raw material equivalent to 7.9 tons of maize, 10.5 tons of soybean, 4. 7 tons of sorghum and 2. 4 tons of wheat (Narrative and financial report of COCOF, 2009). These figures show that soybean comes at the first place with a higher demand. This higher demand in soybean implies that COCOF beneficiaries cannot satisfy the production unit alone. Hence local individual farmers are presented with market opportunities for their produce. For instance, among products sold in 2009 were composite flour (10.1 tons), Tofu (1.1 ton), Okara (the remaining after making milk, residues) (696 kg), Soy flour from roasted beans (104) kg and Soy milk (18 L). The market for these products extended especially in urban areas of Kigali. The growth in market is mainly attributed to population increase, increasing urbanization and change in consumer behaviour. Kigali city is growing faster, the market will grow accordingly.

***Rwanda Agriculture Board (RAB)***

The government of Rwanda has initiated the support in soybean production and recently initiated soya seeds multiplication programme and farmers can access to certified seeds through RAB (Rwanda Agriculture Board and inputs) Rwanda agriculture board provide a big market for farmer cooperatives for high quality seeds. All good quality seeds are sold back to RAB and at a good price.

### 3.7.2 Supply analysis

Information on market opportunities was also gathered from farmers using semi-structured interviews. The existing markets, the distance to the market, time for traveling, means of transport as well as months for highest and lowest prices.

Table 27 Markets available for crop produce

| Region | Markets | Distance to the market (km) | Means of transport | Month of highest price | Month of lowest price |
|---|---|---|---|---|---|
| *Gitare/Kamonyi* | Musumba | 1-2 | Bike, walking | April, August | December, January, June |
| | Gitarama | 6-7 | Bikes, working | | |
| *Nyagihunika/Bugesea* | Nyamata | 5-7 | Bikes, walking | April, August | December, January, June |
| | Ruhuha | 10-15 | Bikes, buses | | |

In Kamonyi, farm gate and retail prices vary greatly as such farm gate prices ranged from 300 to 350 RWF per kg. Retail prices could even be more up to 400 RWF per kg. During planting time in Kamonyi for local market 400 and 450 to 500 RWF for transformation units and agricultural institution. While the process range from 250 to 300 RWF per kg in Bugesera. The results reflect higher in price in Kamonyi and that could be explained by the demand in soybean based products that are highly consumed in Gitarama town and Kigali city.

Table 28 Average soybean produce (kg) for 2011 A, the season before the study season. Proportion kept for home consumption (%) and proportion sold (%) across different farm types

| | Bugesera (n=4) | | | Kamonyi (n=4) | | |
|---|---|---|---|---|---|---|
| | Total | Kept | Sold* | Total | Kept | Sold* |
| 1 | 10 | 87 | 13 | 11 | 89 | 11 |
| 2 | 2 | 100 | 0 | 43 | 38 | 62 |
| 3 | 35 | 43 | 57 | 52 | 22 | 78 |
| 4 | 55 | 59 | 41 | 69 | 23 | 61 |

**Sold proportion includes also the soybean used for casual labour payment*

The average production per farmer in the previous season was 7 kg in Bugesera and 22 kg in Kamonyi for farmers of types 1 and 2. Average production for farmers of types 3 and 4 was 45 kg in Bugesera and 61 kg in Kamonyi. Almost all soybean produce is consumed in resource poor farms while a large proportion of produce is sold in resource rich farms.

### 3.7.3 Market channels for soybean

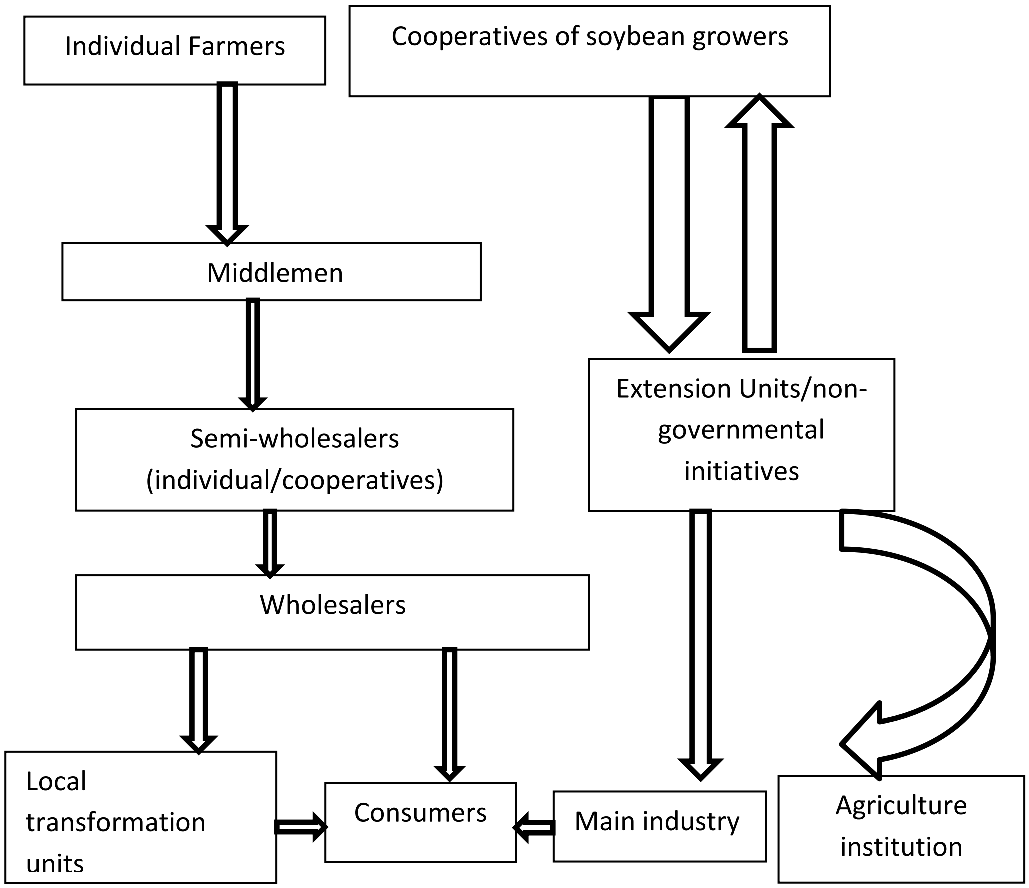



Fig. 9. Soybean market channels

*Channel 1*: (individual farmers- micro-retailers- wholesalers): For this channel, soybean is collected at farm gate in some cases by micro-retailers or retailers who bring it to the local markets and there, semi-wholesalers or wholesalers take it to urban markets or to processing units in urban areas where a big number of consumers dwells. However, with this channel the main question would be on the quality of soybean grains sold and whether the price paid at farm gate is sufficient to sustain the purchase of inputs for another planting season and also to improve livelihood of farmers. It was observed that this market channels limited farmers of farm types 1 and 2 to get access to potential niche markets. This was because, grains were sold immediately after harvest as most of these farmers were in urgent need for money, they accept even low price because at the harvest the prices are low. Besides, their grains are a mix of different varieties and the quality was questionable for the sale to big markets such as SOSOMA Industries Ltd and RAB. Generally, the reinforcement of creation of farmers 'cooperatives can foster small farmers through group marketing and input supply. Low quality of products produce is a big issue for farmers operating to their own as most of their production is intended for own household consumption and in case of sales the price is lower.

*Channel2* (farmers'cooperatives- extension units- main industry): for this channel, farmers work in associations supported by extension agents from non-governmental organizations. Farmers get inputs (certified seeds, inoculant and chemical fertilizers) at planting and the management is monitored by extension workers. Their produce is sold mainly to RAB and SOSOMA Industries Ltd which give a higher price but are only interested in higher quality grains. Channel 2 is more profitable to farmers due to the access to inputs and the access to big markets with a good price. Basically, preferences are different from each category of market depending on the purpose for buying soybean grains. Niches market categories and implication on price are presented in Table 29.

Table 29 Market category and implication on price

| Niche market | Agricultural Institution | Industry | Transformation units | Ordinary consumers | Whole seller |
|---|---|---|---|---|---|
| *Category of grains purchased* | Best quality seeds | Best quality seeds | Both, do not care about the quality | Both, do not care about the quality | Both, do not care about the quality |
| *Unit price(US$/kg)** | 0.8 US$ | 0.8 US$ | 0.5US$-0.7US$ | 0.5US$- 0.7US$ | 0.4US$-0.5US$ |

*1US$=606 RWF

Big industries and agricultural institutions prefer to buy best quality grains because of their use. For agricultural institutions, grains are used for seed multiplication for distribution throughout the country; reason why they need best quality. For SOSOMA Industries, they need to produce healthy food products for the consumers. Others take both good and non-good quality grains because they do not care about the quality.

# 4. Discussion

## 4.1 Cropping patterns

***Land allocation to different crops***

In general, resource poor farmers seemed to have less crop diversity at farm scale and more crops diversity at field scale in both locations. This may be explained by land shortages. Farmers intercrop many crops in the available small plot. Nabahungu and Visser (2011a) reported that resource availability and land ownership have an important impact on the allocation and type of farming systems practiced by households in Rwanda. For both Bugesera and Kamonyi, beans, banana and cassava were cultivated on larger extended fields while soybean appeared to be grown on small areas of land (Fig. 5). Little land allocated to soybean in Rwandese farming systems was also reported by Rutunga *et al.* (2007). Mugabo (2003) reported that one-fifth of cultivated land was located to cassava in Bugesera making it the second most important crop in this region after beans which indicates that outside of the study sites, cassava is the main crop in the region.

Beans, being a staple food in Rwanda, are cultivated at large areas and most farmers have a plot near the homestead for fresh leaves, pods and fresh grains harvested before other beans grains are ready to be harvested. Musoni (2008) found that climbing and bush beans are intensively cultivated in Rwanda on about 30 per cent of the arable land. This is also consistent with the results from the crop assessment by (MINAGRI, 2009; 2010). The higher importance given to beans production may be partly explained by the fact that the annual per capita consumption of 50-60 kg is one of the highest in the world. The importance of cassava in these two agro-ecological zones is mostly explained by the fact that it provides higher edible yield per hectare and higher returns to labour than other crops on less fertile soils (Tables 15 and 21). Some crops were abandoned such as finger millet as was also shown by Reckling (2011).

***Input use***

Farmers used more manure and compost in marshland than on hills because of insufficient manure production. The allocation of organic or inorganic fertilizer to fields was based on the nature of crop to be grown, with higher priority given to vegetables. This agrees with the findings of Tittonell *et al.* (2005a) in Western Kenya that resource availability and the pattern of resource allocation to different activities are determined by household wealth and depend on household priorities and production strategies. According to Nabahungu and Visser (2011a), more than half the fields are never fertilised, especially the remote fields on hillsides, because the total organic matter production is insufficient to supply the needs for all fields. Although farmers used organic and mineral fertilizers, the rate of fertilizer application was below the recommended rate, and almost null in resource poor farmers. Most farmers applied 1-25 kg N $ha^{-1}$, 1-15 kg P $ha^{-1}$ and 2-30 kg K $ha^{-1}$ (Table 10). Nabahungu and Visser (2011b) found that farmers in Rwandese wetland applied DAP to rice at low rate of 50 kg $ha^{-1}$ compared with the recommended 100 kg $ha^{-1}$.

## 4.2 Farmers’ perceived production objectives and constraints

Production objectives and constraints varied between different farm types and across different AEZs (Table 11). It was noticed that among Kamonyi farmers, about one third had at least a small plot of soybean. Actually, Kamonyi district is known as a potential region of soybean cultivation as reported in land suitability for crops in Rwanda by Verdoodt and van Ranst (2006). In Bugesera, most farmers were trying soybean and were not aware of the nutritional value; probably because Bugesera is known as a region with less potential to grow soybean (Verdoodt and Van Ranst, 2006). All farmers consider soybean as a minor crop and they allocate it to a small land area and on marginal land assuming that it is more tolerant to poor soil fertility than other crops. Farmers in Kamonyi were willing to expand soybean production through improved technologies although the incentives on inputs (improved seed varieties, chemical inputs) and lack of knowledge were limiting factors. Farmers in Bugesera are not interested in growing soybean; for them soybean was not preferred for both food and income. This may be partly explained by the commonly grown groundnut which has the same role as soybean according to farmers’ belief.

***Production objectives***

Food and cash were mentioned as the main production objective in Kamonyi. Whereas in Bugesera, food and payment for casual labor were the main objectives (Table 11). The difference in objectives may be due to the difference in markets opportunities in both regions. Rotational and soil fertility benefits of legumes were less known to farmers, as was also observed by van den Brand (2011) in Malawian farming systems. In Bugesera, food was the main objective in farm Types 1 and 2 while cash and food were both considered for farm Type 3. Payment of casual labour and food were considered in farm Type 4. The difference in soybean production objective between different farm types may be explained by the availability and diversity of food within household, the capacity of farmers to invest in the production and the ability to purchase some food as well. In both sites, farmers of Type 1 grow soybean for home consumption. In Kamonyi most farmers seemed to be interested in cash because of the availability of soybean transformation units in which farmers can sell their produce. However, soybean production is still low.

***Constraints***

This study showed that each particular farm type in particular AEZ appeared to have specific constraint in soybean production. In general, drought and low market prices were ranked as main constraints of soybean production in Bugesera. Drought occurrence was mentioned in all farm types as this AEZ is known to have less rainfall and when available, it is erratic. Seeds and land availability were the main constraints for farm Type 1. Lower market prices were mentioned in other farm types (cf. Table 11). This difference reflects the difference in economic characteristics of these farms. Lower market price was mentioned because no soybean transformations units or industries are found in this region. In Kamonyi, labour for farm Type 2 was mentioned as most these households were widow/female headed, because active persons were less in these farms. Although farmers of Types 3 and 4 were able to purchase chemical inputs, they did not know about them. This shows a poor linkage between extension services and soybean growers.

Production objectives and constraints across different farm types and across regions gave the insight on how soybean production is affected by socio-economic and biophysical characteristics of particular farm type and particular AEZ and guided us to answer our research question 1: ’’ What are farmers’ perceptions on soybean across different farm types? Are soybean production objectives and constraints the same among different farm types?''

This study showed that there are diverse and mixed views on soybean production objectives and constraints across different farm types in different AEZs. It was clear that the objectives differed among farm types for several reasons: difference in farmers' resource endowment, ecological characteristics and market opportunities.

This study showed that drought occurrence and access to market are major limiting factors affecting soybean production in Bugesera. Climate explained to a large extent the variation observed in soybean production between the two AEZs. Given that soybean is drought sensitive than groundnuts led to promotion of groundnuts rather than soybean in Bugesera. Water stress and drought stress are major constraints to the production and yield stability of soybean (Manavalan, et al., 2009). The author stated the drought escape as one of the mechanisms to cope with drought stress which allows plant to complete the life cycle during the period of sufficient water supply before the onset of drought. Researchers reported the use of early maturing cultivars of soybean to cope with drought stress (Heatherly and Elmore, 2004). In this regards, it seems that soybean should not be promoted in Bugesera region unless short duration cultivars are introduced that may cope with the drought stress. Besides, lack of markets seemed to be a challenge. The initiation of transformation units and the agreement between farmers and processors on terms of the quantity to produce in order to satisfy the supply are needed.  Also, the price that can stimulate farmers and to ensure the sustainability of the market are needed. This could result in a good income generation to farmers since the products from local transformation units may be sold in Kigali city where a great number of consumers dwell. Kigali city is growing faster, the market can growth accordingly. In addition, farmers training on soybean transformation for households' nutrition may result in the adoption of soybean cultivation in the region.

### 4.3 Legume productivity, N content and partial N balance

#### 4.3.1 Soybean productivity relative to common bean

***Soil fertility***

Soil fertility was significantly different between resource poor farm and resource rich farms in Bugesera with higher soil organic carbon found in resource rich farms than resource poor. No significant difference was observed across different farm types of Kamonyi.

In terms of fertility per crop, significant differences were observed. Fields under main crops such as common beans, intercropping of beans and banana, or cassava were found to be most fertile while fields under sole soybean were least fertile. Farmers' perceptions of soil fertility correlated with measured fertility parameters. Kamonyi farmers allocated soybean to less fertile fields assuming that this is more tolerant to poor soils. Also Bugesera farmers neglected soybean and grew it on poor soils. Besides, crops cited as main crops by farmers were found to be grown on more fertile fields.

Significant difference was obtained between home fields and outfields for almost all soil fertility parameters. The effect of field distance on soil fertility was also significant between home fields and middle fields except in exchangeable Na, total N and total C. There was no significant difference observed in soil fertility between middle fields and outfields.

Many researchers reported gradients of decreasing soil fertility with increasing distance from homestead within smallholder in African farms (Giller, et al., 2006; Tittonell, et al., 2005b; Zingore, et al., 2007). Tittonell et al. (2005b) found soil fertility gradient if farming systems of western Kenya and they argued that internal heterogeneity in resource allocation varies according to farmers' objectives and factor constraint. Soil fertility varies markedly within and between African smallholder farms, both as a consequence of inherent factors and differential management. Fields closest to homestead (home fields) typically receive most nutrients and are more fertile than outlying fields (Zingore, et al., 2007). They reported greater soil organic carbon, available P and exchangeable bases on the home fields than outfields. Farmers preferentially allocate manure, mineral fertilizers and labour to fields close to homestead, resulting in strong negative soil fertility gradients away from the homestead (Giller, et al., 2006). In this study due to small size in farms, most out fields are situated on short distances even less than 50 m from homestead. Similar was documented in Zimbabwe on small farms of less than 3 hectares and within distances of less than 50 m from homestead (Mtambanengwe and Mapfumo, 2005; Zingore, et al., 2007).

From the analysed data, soil fertility is higher in Bugesera than in Kamonyi due to highest chemical indicators except in the case of available P. Resource rich farmers' fields seemed to be more fertile compared with resource poor farmers' fields in Bugesera. Similar was reported by Rutunga *et al* (2007) that in lowlands including Bugesera region, soils are relatively higher in nutrients compared with other regions but dry spells are limiting production.

***Biomass production, grain and stover yields***

Generally, the higher biomass was obtained in Bugesera than in Kamonyi for both common beans and soybean in all farm types except in farm Type 1 (Table 16). However, the higher soybean biomass obtained in Bugesera did not correlate with grain and stover yields. These in contrast were higher in Kamonyi than in Bugesera in all farm types (Table 16), probably because of drought sensitivity of soybeans. According to Rutunga et al (2007), in the eastern part of Rwanda rainfall events are erratic and drought or excess rainfall may cause yield losses from 25 to 100 per cent in the region. Soybean is reported to be sensitive to water stress by many researches (Manavalan, et al., 2009; Sinclair, et al., 2007). Soybean reproductive stage is known for its sensitivity to drought stress (Kpoghomou, et al., 1990). From the study conducted in Rugeramigozi (Wetland near Kamonyi) by Nabahungu (2012), soybean produced more biomass in most landscape positions than beans. In his study, soybean biomass were around 750 kg $ha^{-1}$ in hillside, 2000 kg $ha^{-1}$ in foot slope and around 1000 kg $ha^{-1}$ in wetland. Our results from Kamonyi are quiet similar to the findings of Nabahungu (2012) with a range of 1200-1500 kg $ha^{-1}$ but differed in terms of soybean producing less biomass than beans.

In Bugesera, common beans have higher dry grain yield than soybeans in all farm types while in Kamonyi soybean had higher grain yield in farm Types 3 (Table 15). These results are consistent with what Nabahungu (2012) found in Rugeramigozi but different from what they found in Cyabayaga. This shows that not always soybean grain yields are less than beans because in some locations soybean can yield more than beans and this can be partially explained by differences in crop management such as weeding for example. Vandeplas *et al.* (2010) found that 5 per cent grain yield of soybean was lost by weeding once instead of twice in South-

Western Kenya. Also, our study showed that soybean yields were higher than the yields of groundnuts in all farm types.

***Nodulation***

Generally, a higher nodulation was observed in Kamonyi than Bugesera, especially in soybeans. Perhaps, because Kamonyi farmers used more manure compared to Bugesera farmers. It has been reported by researchers that manure lead to increase in indigenous rhizobia numbers. Higher organic matter input from manure amendments could improve survival and persistence of rhizobia that live as saprophytes in the soil until the next legume crop is planted (Zengeni, et al., 2006) and this has been confirmed in their study that manure application significantly influenced population sizes of rhizobia with numbers increasing with increasing manure rate. The same was reported by O'Hara (2001) that organic matter plays an important role in the mineral nutrition of rhizobia in the soil by acting as a source of C, N, Ca and S required for their growth and survival. Furthermore, manure also has a liming effect, which neutralizes the acidic conditions characteristics of most smallholder soils (Nzuma, et al., 1997) this could in turn provide favourable conditions for rhizobia survival (Zengeni, et al., 2006).

Farmers in Rwanda do not practice any inoculation, and are not aware of the technology. Farmers' fields may be poor in rhizobia populations and the use of manure can be regarded here as an advantage in terms of nodulation improvement. As reported by Zengen, *et al.* (2006), soils without a history of soybean inoculation had very low populations of rhizobia ranging from 0 to 29 cells $g^{-1}$ of soil.

### 4.3.2 Legume N content and nutrient balance

***N content in soybean and beans***

Soybean has been reported by many researchers to fix higher amount of N compared to other grain legumes (Giller, 2001; Hungria, et al., 2006; Peoples, et al., 2009; Unkovich and Pate, 2000). It has been widely shown that up to 80 per cent of the aboveground N accumulation in soybean can be due to N fixation by rhizobia. According to Peoples *et al* (2009) on overage, common beans might be expected to fix < 50 kg shoot N $ha^{-1}$, while soybean generally fixes > 100 kg shoot N $ha^{-1}$. Furthermore, Unkovich and Pate (2000) suggested a potential for $N_2$ fixation by nodulated soybeans of 360-450 kg of N $ha^{-1}$.

Average N concentration was higher for soybean than beans. In Bugesera, soybean average N concentration was 5.6 per cent and 0.89 per cent in grains and stover respectively. Common bean had an average N concentration of 3.75 per cent and 1.17 per cent in grains and stover respectively. In Kamonyi, soybean had the average N concentration of 6.21 per cent in grains and 0.86 per cent in stover whereas common bean had 3.43 per cent in grain and 1.35 per cent in stover. Higher N concentration in soybean than beans was observed elsewhere in East Africa; for instance, Wortmann and Kaizzi (1998) found N concentration in soybean to be 5.20 per cent and 1.00 per cent in grains and stover respectively and N concentration in beans to be 3.30 per cent in grains and 0.80 per cent in stover in farming systems of Uganda. Van den Bosch *et al.,* (1998) reported grains N concentration of 4.1 per cent in beans in farming systems of Kenya.

It has been reported that for grain legumes to play an important role in maintenance of soil fertility for other crops in rotation, they must leave behind more N from $N_2$-fixation than the amount of soil N that is removed in the crop (Giller, 2001). According to the author, the two purposes served by crop; one to provide grain yield and the other to leave residual N are somewhat contradictory. At both locations, soybean higher N export in grains and stover were obtained in resource rich farms (Types 3 and 4) than in resource poor farms (Types 1 and 2) probably due to high DM yields obtained in resource rich farm than in resource poor farms. Most grain legumes have been found to remove more N from the soil than they leave behind because of their higher N harvests indices of up to 0.90 (Eaglesham, et al., 1982; Toomsan, et al., 1995). In this study, nitrogen harvest index (NHI) ranged from 0.8 to 0.9 for soybean and from 0.7 to 0.8 for common beans. Although soybean has higher NHI than common bean, soybean yields were far less the yields of common bean in Bugesera. The proportion of N exported as grain in soybean was greater than in common bean in Kamonyi and the reverse was observed in Bugesera. Soybeans have been reported to export more N in grains by many studies. Nitrogen harvest index of soybean is often high; N accumulated in seeds may represent more than 85 per cent of plant N for soybean (Toomsan, et al., 1995). In the study conducted by (Nabahungu, 2012) in Wetlands of Rwanda, higher N export through legume grain harvest was observed in common bean than soybean in Rugeramigozi wetland and lower N harvest in common bean than soybean was observed in Cyabayaga wetland. Probably differences in grains yields can explain this variability among different regions of Rwanda. Taking into account the difference in N concentration between soybean and bean grains, in case yields can be optimized for both legumes, higher N export can be found in soybean rather than in beans. In this study, both soybean and common bean led to a negative net N input even if the stover were to be returned to the fields. But N deficit was less when stover were to be returned to the fields. Tropical grain legumes such as soybean are efficient in translocating the bulk of the fixed N to the grain, and even when residues are returned to the soil, there may be a net removal of N from the field (Peoples and Craswell, 1992). However, this depends on the cultivars and the field history (Peoples, et al., 1995).

This study showed that net input from $N_2$-fixation for both soybean and common bean differed across sites. N deficit was greater in common bean than in soybean in Bugesera and the reverse was observed in Kamonyi. This is probably explained by the lower soybean grain yields and lower N concentration obtained in Bugesera compared with common bean. The reduction factor of deficit when residues are retuned was almost similar for both soybean and common bean, except in farm Types 2 and 4 in Bugesera where a greater reduction was observed when soybean residues are returned to the field than when common bean residues are returned to the fields (cf. Table 20).

***Field level partial nutrient balances***

Field level partial nutrient balances were calculated taking into account organic and inorganic fertilizer use. When all stover were to be removed from the field, nutrient balances soybean were negative in all farm types of Bugesera while positive soybean nutrient balances were observed in Kamonyi. This may be attributed to little use of fertilizer inputs in Bugesera where most farmers did not apply any manure or chemical fertilizer in soybean fields. Kamonyi farmers applied more manure to soybean resulting in positive balances. Similar trend was observed in common bean partial nutrient balances. In Bugesera, negative balances were observed in all farm types except farm Type 4. Farmers of Type 4 applied more manure in beans fields which resulted in higher balances compared with other farms. Differences in nutrient balances for different crops and different farm types can be attributed to the priority given to crops in fertilizer inputs use. Both beans and soybean depleted soil more in Bugesera than in Kamonyi. Negative N balances for both beans and soybean were reported in Rwanda; Nabahungu (2012) reported lower N balances for common beans (approximately -18 kg $ha^{-1}$) than soybean (approximately -2 kg $ha^{-1}$) on hillside of Rugeramigozi wetland near Kamonyi. However, more negative N balances were reported by Wortmann and Kaizzi (1998) in farming systems of Uganda with -121.5 kg $ha^{-1}$ and -40.4 kg $ha^{-1}$ balances for soybean and bean respectively.

Assuming that all crop residues are returned to the fields, nutrient balances were improved in all farm types in both locations with higher positive impact in Kamonyi than in Bugesera. In Bugesera, nutrient balances for soybean remained negative in all farm types. This can be attributed to lower stover yields obtained in Bugesera, hence returning crop residues to the fields did not add much. It has been reported that in many cases there is no net benefit from including a grain legume in the crop rotation, even when the legume stover is returned to the field (Giller, 2001). These results show that if, however, the stover were returned, soybean would deplete more in all farm types of Bugesera. In Kamonyi, returning soybean residues to fields improved nutrient balances due to higher stover yields obtained. However, differences livestock numbers across the two sites explained a lot the differences in nutrient balances. Farmers in Kamonyi own more cattle than farmers in Bugesera, they applied more manure in different crops than Bugesera farmers (cf. Table 10). These results highlight the importance of manure in smallholder farmers in farming systems of Rwanda.

Although nutrient balances were negative, there may be a positive effect to the subsequent crops. Contribution of legumes residues to soil fertility improvements have been reported (Toomsan, et al., 1995) and soil N enrichment has been attributed to the residual effects of legumes or legume sparing effect. According to Mpepereki et al (2000) some promiscuous soybean cultivars have indeterminate growth habit and have relatively lower grain and N harvest indices, and hence have greater potential to add N to the soil than specifically nodulating soybeans. Furthermore, overall, soybean has been shown to have residual soil fertility benefits regardless of variety or type (Kasasa, et al., 1999). However, the usual farmers practice in Rwanda is to harvest the crop without returning the stover to the field. Carsky et al (1997) reported that even when the stover was exported, maize grain yield increase following soybean that was given a basal application of 20 N $ha^{-1}$ was similar to that from 40 kg N $ha^{-1}$applied to maize preceded by maize in Guinea Savanna of West Africa.

Field partial nutrient balances were calculated based solely on above-ground plant parts. N balance could be improved when considering the contributions from fallen leaves, roots and nodules. In the field, below-ground N represent around 30 per cent of N plant and rhizodeposited N often accounted for 88-97 per cent of below-ground N (Fustec, et al., 2010). Since roots and rhizodeposits are so rich in N, including a grain legume in rotation may lead to a positive N-preceding effect on the following crop, despite N losses due to harvest (Fustec, et al., 2010). However, Kasasa et al. (1999) reported that contributions from fallen leaves and below-ground soybean plant parts gave significantly higher maize DM and grain compared with control (maize-maize) in Zimbabwe.

## 4.4 Contribution of soybean to farmer's income

Lower yield was a major factor affecting the income from soybean production. The study showed that growing soybean resulted in negative net return across almost all farm types in Bugesera and positive net return in Kamonyi (Table 21). The difference is due to lower yield obtained in Bugesera than in Kamonyi and soybean market availability with more markets in Kamonyi than in Bugesera. Although soybean net return was higher in Kamonyi compared with Bugesera, the overall net return from soybean was lower compared to groundnuts, common beans and cassava. For cassava, it has higher yield on an area basis while the higher net return for groundnuts was due to relatively high local market price when compared to other grain legumes. However, groundnuts have lower land productivity and are produced in less cropping systems when compared with common bean and soybean. Lower and negative net return observed for soybean are explained by low investments in terms of fertilizer inputs use and the fact that most farmers grow it on marginal land giving low yields, hence lower returns. Mugabo (2010) also reported that in Rwanda, soybean growers are not familiar with the use of mineral fertilizers.

***Contribution of soybean to household income in improved techniques scenario***

The results show positive net returns in all farm types, except in farm Type 1 of Bugesera. In Kamonyi, improved techniques scenario gave higher soybean net return in all farm types compared to Bugesera with highest net return in resource rich farms than resource poor farms. Although, the net return of soybean increased in improved techniques, in Kamonyi, soybean net return remained low compared to groundnut in farm Types 3 and 4 and was low compared with cassava and groundnuts in farm Type 2. In Bugesera, soybean gave higher net return than other crops in farm Types 2 and 3, while in farm Type 4 net returns for cassava and beans were higher compared with soybean (Table 22). These can be attributed to very low soybean grain yields obtained by farmers. Average soybean grain yield was 483 kg $ha^{-1}$ in Bugesera and 689 kg $ha^{-1}$ in Kamonyi which are far less compared with soybean grain yields in control plots managed by researcher in N2Africa where the average was 1211 kg $ha^{-1}$. Reasons here are diverse; planting pattern, planting date, weeding and soil fertility which may be different between farmers plots and research managed plots.

This study showed poor soybean grain yields ranging from 219 kg $ha^{-1}$ to 800 kg $ha^{-1}$ due to the allocation of the crop on marginal land and poor management. Almost similar findings have been reported by Vandeplas *et al* (2010) in South-Western Kenya where soybean grain yields in plots without inputs was found to be 537 kg $ha^{-1}$. They reported an increase of 27-51 per cent for both soybean grain and biomass yields under inputs use conditions. They concluded that there is large yield gap between the average yields obtained by farmers and the experimental yields obtained by researchers in the same environmental conditions but using available 'best-bet' technologies.

The benefits of soybean to smallholder farmers in terms of income have been reported elsewhere for instance, Mpepereki *et al.* (2000) reported that in many parts of Malawi, Zambia and Zimbabwe smallholder farmers were earning modest farm incomes from their soybean crops, thereby boosting rural economies and alleviating poverty. Similar was reported in northern Tanzania by Ndakidemi *et al.* (2006) that soybean offered resource-poor farmers better returns and higher dollar profits than common beans with bacterial inoculation.

## 4.5 Contribution of soybean to household food security

On unit area basis soybean did not contribute much to energy production because is grown in most cases in remote fields. Given that soybean protein content is higher than any other crop; soybean protein production on a unit area basis was the first at both locations. In terms of total energy and protein production, soybean was the least in energy provision in all farm types of both locations. Also soybean protein provision was lower compared to other crop except cassava which provided the lowest protein. Little area allocated to soybean production results in small produce at household level giving lower energy and protein. Energy and protein from soybean were higher in resource rich farms than in resource poor ones due to higher produce obtained in resource rich farms than in resource poor farms. However, this study showed that soybean is mostly consumed by resource poor farmers.

Land availability was found to be less in poor households than in wealthier ones. The diversification in food production was limited and therefore the nutritional requirements on the poor households may be hard to access. This may explain why more food insecurity was observed in resource poor households. The National Institute of Statistics in Rwanda, NISR *et al.* (2006) showed that 14 per cent of households in Rwanda are in poor consumption profile considering the diversity of the diet. For both Bugesera and Kamonyi most resource poor households were food insecure (Table 26). Matai (2007) reported that among factors that correlated with food insecurity in Rwandan community land size was the first, where 41 per cent of people who cultivated less than 0.1 ha were food insecure compared to 21 per cent or less for those cultivating 0.5 ha or more. More food insecure households were found in Bugesera than in Kamonyi which is consistent with REMA (2009) report that percentage of food insecure households are between 36-40 per cent in Bugesera region and 26-30 per cent in central plateau region in which Kamonyi District is located.

***The implication of improved techniques scenario to household food security***

Improved techniques scenario increased both energy and protein production of soybean in all farm types compared to current production system. However, total soybean contribution to energy availability at farm level remained low when compared with major crops due to little land allocated to the crop production. But soybean contribution to protein was higher than any other crop except beans (Table 25). This shows the greater contribution of soybean production to protein production. The results are in line with the findings by Rutunga *et al.* (2007) and Mugabo (2010) that the constraint for soybean production in Rwanda is the little land allocated to it. In addition to little land allocated to soybean, the study showed that most farmers grow soybean on marginal land which could also be a limiting factor of soybean benefits to household.

### 4.6 Market opportunities

The accessibility of the crop to special markets gives it a higher value and stimulates farmers to invest in that crop. Basically, preferences are different from each section of market depending on the purpose for purchasing soybean grains (Table 29). Agricultural Research Institution needs best grain for seeds multiplication programme and big processors such as SOSOMA Industries also need grain of higher quality while local transformation units can purchase any quality of grains. At the local markets, farmers may sell grains of any quality but still the price is low which lower the income from soybean. This study showed that access to big markets which give a good price depended on the quality of grains produced. Farmers need to switch to the improved technology such as adopting the use of certified seeds, agricultural inputs and improved management which in turn give higher quality produce.

Production of soybean will be enhanced by the improved profitability by linking soybean growers to more profitable markets. More researches indicated that sustaining success in productivity-based agricultural growth critically depends on expansion of the market opportunities (Diao and Hazell, 2004; Gabre-Madhin and Haggblade, 2004). Our findings show that the market opportunities and soybean marked proportion vary among different farm types with higher marketed proportion in resource rich farms than in resource poor farms. This is explained by little produce in resource poor farms. In addition, soybean was found to be consumed mostly by resource poor farmers. Difference in marketed proportion among different classes of farm households in the same production system has been also reported by Tripp (2011). Besides, the demand and supply analyses showed little supply compared with demand in current production.

The analysis of market channels shows that the market channel involving middlemen touch the life of farmers belonging to farm Types 1 and 2 particularly. Firstly, access to big markets had been impossible for them without the role of middlemen. This is because their sales are little, need to be collected together. Also, the quality of their grains is questionable (cannot be accepted at the big market). Secondly, farmers using certified seeds sell grains to big market with good prices. The use of mixed varieties of seeds at planting, non-use of input was the main factors constraining the quality of grain produced. These limit farmers to get access to the markets that offer higher prices. In this regard, there is evidence that new technologies brought by N2Africa project to farmers can improve the yield and quality of grains. Thus, pave the way for access into good markets and possibilities for price increase, and income to rise.

In addition to the existing soybean markets, a new soybean oil processing industry (SOYCO) is being installed in Kayonza, Eastern Rwanda which will be ready in April, 2013 according to MINAGRI strategic plan. The industry is expected to increase the demand for soybean as raw material to more than 26,000 T per year. Rwandan Government is developing strategies to enhance soybean production through MINAGRI and RAB. Among strategies, RAB will initiate seed multiplication in collaboration with farmers, farmers' trainings, establish participatory trials and increase inoculants production. This promises big market opportunities to soybean growers in the future which will result in soybean intensification in Rwandese farming systems in order to ensure enough supply from local farmers. The possibilities here will be the inclusion of soybean in rotation with maize in the programme of land consolidation in which soybean can be grown twice a year in growing seasons A and C in marshlands. The challenge here will be the price provided by the industry in order to stimulate farmers to invest more in soybean production.

The success in soybean promotion was reported in some countries of Africa and came from the proper coordination generated by policy support and incentives which ensures that processors and producers get along on mutually beneficial terms. Chianu et al. (2009) concluded that addressing issues of market is a key element of sustainable development and rural growth in Africa and highlighted the importance of the'' whole soybean'' approach (production, processing, marketing and utilization) instead of focusing only on production. It has been reported in Zimbabwe, that the successful soybean production was due to the linkage of smallholder soybean producers with industrial processors and the great role of public policy support. Also, household and community level processing and linking farmers to supermarkets and large-scale food processors (Chianu, et al., 2009).

## 4.7 Niches for intensification

The identification of possible niches for soybean intensification and the resulting trade-offs are elaborated and our fourth research question "Where are potential niches for expansion of soybean production in Rwandese farming systems'' is answered here.

The overall goal for the identification of potential niches for soybean intensification in Rwandese farming systems is an increased protein availability to sustain food security, especially to poor households and exploit market opportunities to improve farmers' livelihood. In addition, assuming that soybean has a higher $N_2$-fixing capacity compared to other grain legumes, the intensification of soybean cultivation can result not only in increased food security and income to smallholder farmers but also in improved farming system by improving soil fertility.

In order to identify a niche for a crop, its multiple uses need to be taken into account. In Rwanda, soybean is cultivated for food (fresh and dry grain; transformed in some products). Soybean is also cultivated for cash (dry grain and soy products are sold to local markets and transformation units). It provides feed to animals (crop residue, okara and other industrial processed feed). Different uses can be complementary but also lead to direct trade-offs (Giller, 2001) and this is especially in the case of the use of crop residue either for feeding animal or for soil fertility. Taking into account the problem of land scarcity is Rwanda; soybean intensification can be achieved through increased productivity on the unit area basis by the adoption of improved techniques.

***Improved Techniques***

Although no recent data available on soybean production in Rwanda, several researches have been conducted before 1990 and reported a response of soybean to improved technologies. The increases in yields were associated with the increase in protein and lipid content. For instance, in trials conducted at Gihindamuyaga (South of Rwanda) by Ndamage (1978) showed that inoculation increased the protein content by 12.5 per cent and Bukeye (1982) at Karubanda found the increase of 41 per cent. Trials at ISAR Rubona by Hakizimana (1982) in collaboration with plant production department found that inoculation was accompanied by 50 per cent increase in yield of dry grain and 210 per cent increase in lipid content. Ndakidemi, et al. (2006) also reported a strong response of soybean to inoculation in northern Tanzania where grain yields increased by 127-139 per cent from inoculation alone and 207-231 per cent from inoculation together with phosphorus fertilizer application. These show the importance of inoculant use by smallholder farmers, especially resource-poor farmers who are unable to afford expensive chemical fertilizers. In terms of soil fertility improvement, Bukeye (1982) concluded that rhizobium in symbiosis with soybean fixed 254 kg nitrogen $ha^{-1}$ in which 171 kg were harvested with soya and the remaining 83 kg in the soil constituted the nitrogen input in the soil. To date, local inoculants production in Rwanda is still insufficient; hence the speed of eventual adoption of technology can be affected.

***Potential niches as affected by different farm types and different regions***

In Kamonyi, farmers were aware of the nutritional value of soybean; knew how to prepare various recipes from soybean but still the consumption habit and preference limited the inclusion of soybean in their diets, especially in resource rich households. The existence of soybean transformation units in the region provide an opportunity to farmers which could result in market niche. However, because of the lower grain produce and lower quality of produced grains most farmers are limited to access to big markets with good prices. This lowers the income from soybean because the prices obtained at farm gate and local markets are low compared with prices at big markets.

In cropping systems of Kamonyi, a soybean niche can be found for all farm types in intercropping with cassava (a common practice is intercropping legumes with cassava), this can be an option for soybean expansion because farmers use it as a means of weeding cassava and for them this is considered as labour and land saving technique. Pypers *et al*. (2011) reported the increase in beans yields intercropped with cassava and the increase in revenue. This could be a suitable niche for beans and soybean especially in those land limited households. Although, soybean has been reported to have negative effects on cassava yields when intercropped because of its higher biomass production and long maturity period by some researchers (Pypers, et al., 2011), other researchers showed the positive benefit of soybean to cassava yield, Makinde, *et al.* (2007) reported the increase of 10-23 per cent in cassava yields due to soybean residues incorporation. More studies are needed to find how well soybean may fit in this intercropping. Probably early maturing varieties can be regarded as an option, or limit soybean growing in the first season as reported by in Pypers *et al* (2011) in highlands of Sud-Kivu, DR Congo. Farmers in Rwanda do not use any planting pattern such as planting in rows. Probably, planting in rows using wider spacing can be an option. But still research is needed.

Farmers of Types 3 and 4 have opportunities to expand soybean cultivation. They own plots in marshlands that can be used to grow soybean in rotation with maize. Also, the organization in farmers' cooperatives is easier in resource rich farms where plots in marshlands can be used. Second, these farms have access to inputs whereas resource poor farmers are unable to access to chemical inputs and improved seeds. Farmers of Types 1 and 2 are limited by financial means and cannot wait until the harvest of the crop as they always need to harvest fresh grain before the final harvest. The challenge for expanding soybean cultivation in resource rich farms would be the less competitiveness in income generation compared to staple crops.

As was shown in this study, mostly soybean was grown in remote fields and fertilizer inputs use was less compared to major crops. Once soybean can be grown in the same conditions as major crops, the crop can give higher yields. Since soybean has good price compared to major crops and its market is currently expanding, the crop may be more profitable than other crops.

For better benefiting from $N_2$-fixed by soybean, the introduction of later maturing soybean varieties but higher biomass yielding may be seen as an option in terms of BNF in resource rich farms. Since these farmers have access to agricultural inputs, the use of higher yield potential soybean varieties together with inoculants can be a more profitable technology as soybean responds well to inoculation in Rwandese soils. This could result in the improved farming system in terms of BNF, as longer maturing varieties are reported to be more efficient in $N_2$-fixation (Giller and Wilson, 1991; Larue and Patterson, 1981; Ogoke, et al., 2003). As reported by Peoples *et al.* (2001), $N_2$-fixation is regulated by legume biomass production rather than by %Ndfa and one of means to enhance $N_2$-fixation is through increasing legume biomass. Such technologies would require more labour and investments; still these farmers can cope with it by hiring labour since they have relatively enough financial means. Although farm Types 3 and 4 are able to access to inputs, the availability of those inputs in their localities and the lack of knowledge were main constraints to them. All technologies involving extension services to those farmers would result in the adoption of legumes.

As mentioned in (Giller, 2001), the two purposes served by crop; one to provide grain yield and the other to leave residual N are somewhat contradictory. Legume technologies for farmers of farm Types 1 and 2 need to address the home consumption and subsistence aspect and the low availability of resources. The relevant technologies are those that increase yields and food self-sufficient facilitated by the access to inputs (good varieties, inoculants and chemical fertilizers. Early maturing varieties can been seen as suitable for these farmers. Besides, land scarcity and higher price of seeds were the main constraint in these farms. All technologies involving intercropping and the facility to access to inputs would be suitable in these farms.

This study shows that soybean production technologies are also AEZ dependent, with specific technologies for specific AEZ. In Bugesera, the niche within the farm could be the intercropping soybean with cassava, banana and coffee plantations as was practiced by some farmers. But this is only possible for resource rich farmers who do own banana and coffee plantations. However, Bugesera farmers are not interested anymore in soybean cultivation, if no measures taken, the crop may disappear from the region. Soybean was least in net return in all farm types of Bugesera. However, shown to be the first together with beans, in protein production per unit area. Groundnut was preferred in terms of food and cash due to good market price whilst was no market option for soybean. Besides, drought occurrence impedes soybean production in the region, leaving a room to groundnut expansion as it is found to be drought tolerant. In this regard, the introduction of early maturing soybean varieties could cope with the environmental stress. Although groundnut was preferred by farmers, it had lower yields compared with beans and soybean. In addition, groundnut was found in less cropping systems compared to beans and soybean. Farmers' motivation to grow soybean would be challenged by lower net return when compared with other crop. The same as discussed for the case of Kamonyi, currently, soybean is less competitive due to the fact that all farmers grow it on marginal land. Moreover, in Bugesera, farmers never apply any fertilizer to soybean. Once, farmers manage soybean fields as they do for major crops, the yields can increase. The initiation of local soybean transformation units may also play role since there was no soybean market available in this region.

Niches for soybean are currently found in intercropping with cassava on hill plots and in marshland plots where soybean can be grown in rotation with maize. Although, marshland plots seemed to be a potential niche for soybean, farmers prefer to grow vegetables in those fields rather than soybean. The Rwandan government is currently promoting maize production in land consolidation programme and the crop removes large quantities of nutrients from the soil and requires substantial N applications for optimum yields as it has been reported in many researches in African farming systems. Inclusion of soybean in rotation with maize could improve maize yields resulting at the same time in soybean intensification.

In this study, soybean was found to be more consumed by resource poor farmers than resource rich farmers. Almost all production is consumed in homestead primarily as porridge for children, soup made from flour of roasted grain, fresh grain or as beans. Mixed with vegetable *(ikimemeti*), also with maize and cassava to make (*bidia*) which is staple paste made from maize and cassava flour. The crop came first in protein production on unit area basis. Resource poor farmers constitutes a great number of the population, thus should be the focus of research efforts given the crop's nutritional merits.

Farmers of Type 3 and 4 will not eat soybean for various reasons: less preference of its taste and the fact that they have alternative food. For these, soybean cultivation is seen as appropriate only for commercial farming where the crop can be used for industrial processing. Food made from soybean processing were found to be the most acceptable in cities. The growing market is an evidence for soybean to become a major crop in the future.

Different farm types have different opportunities to grow soybean. This study highlights that difference in farmers' resource endowment result in use of different farming practices with different objectives and constraints to grow soybean. Niches for soybean intensification in Rwandese farming systems therefore are highly farm type and AEZ dependent.

## Conclusions

This study focused on soybean farming systems and explored potential niches for legumes technologies while taking into account role of different crops and difference in farmers' resource endowment. However, the study of only one season limited the scope of the study.

In Kamonyi, the study showed that source poor farmers make use of soybean compared to resource rich farmers in terms of nutritional role of soybean. They use it in many recipes in their homesteads. Almost all production is consumed in homestead. The crop came first in protein production on unit area basis. As resource poor farmers constitutes a great number of the population, thus should be the focus of research efforts given the crop's nutritional merits.

Resource rich farmers have more opportunities to expand soybean production than resource poor farmers. They do have potential; more land and financial means to get inputs. The challenge would be the little competitiveness of the crop in terms of yield and income. If come to increase yields, soybean can be more competitive in terms of income because market is expanding. These farmers will not eat soybean for various reasons. For these, soybean cultivation is seen as appropriate only for commercial farming where the crop can be used for industrial processing. The growing market is an evidence for soybean to become a major crop in the future.

Ecological characteristics have an influence on the type and variety of legumes adoption. Drought occurrence was major limiting factor affecting soybean production in Bugesera and farmers cultivated groundnuts that are drought tolerant. In this regards, it seems that soybean should not be promoted in Bugesera region unless short duration cultivars are introduced that may cope with the drought stress. In Kamonyi, currently, soybean niches are found in intercropping with cassava. The integration of soybean in cassava based cropping seems to be a way of soybean intensification. Studies are required to find out how soybean may fit in cassava based cropping systems before we draw such conclusion.

To date it is not yet clear the importance of soybean in Rwandese farming systems. In the future; soybean can become a major crop given that the government is promoting maize production in land consolidation programme in which soybean can be used as rotational crop. Besides, the market is expanding; new processing industries are being initiated.

This study highlights that difference in farmers' resource endowment result in use of different farming practices with different objectives and constraints to grow soybean. Niches for soybean intensification in Rwandese farming systems therefore are highly farm type and AEZ dependent.

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## Appendices

Appendix 1. GPS coordinates of studied households

| Bugesera | | | Kamonyi | | |
|---|---|---|---|---|---|
| Farm ID | coordinates of homestead | | Farm ID | coordinates of homestead | |
| Br1 | S02,11’39.1’’ | E30,04’15.0’ | Kr1 | S02,06’28.9’’ | E29,48’23.0’’ |
| Br2 | S02,12’44.4’’ | E:30,03’49.4’’ | Kr2 | S02,06’12.7’’ | E29,48’12.0’’ |
| Br3 | S02,11’57.2’’ | E30,04’17.8’’ | Kr3 | S02, 06’06.9’’ | E29,48’21.8’’ |
| Br4 | S02,13’10.8’’ | E30,03’58.4’’ | Kr4 | S 02,06’10.6’’ | E29,48’22.2’’ |
| Bw1 | S02,13’06.8’’ | E30,03’57.2’’ | Kw1 | S02,05’53.2’’ | E29,48’19.0’’ |
| Bw2 | S02,13’08.7’’ | E30,04’07.0’’ | Kw2 | S02,05’52.6’’ | E29,48’29.3’’ |
| Bw3 | S02,12’12.4’’ | E30,04’27.5’ | Kw3 | S02,05’59.4’’ | E29,48’28.3’’ |
| Bw4 | S02,12’30.7’’ | E30,04’13.4’ | Kw4 | S02,06’14.6’’ | E29,48’50.9’’ |
| BP1 | | | Kp1 | S02,05’30.3’’ | E29,49’02.1’’ |
| Bp2 | S02,13’09.4’’ | E30,03’56.6’’ | Kp2 | S02,05’29.4’’ | E29,49’01.1’’ |
| Bp3 | S02, 12’09.0’’ | E30,04’28.2’’ | Kp3 | S02, 05’35.4’’ | E29,49’13.5’’ |
| Bp4 | S02,11’57.6’’ | E30,04’12.3’’ | Kp4 | S02,05’21.9’’ | E29,49’02.7’’ |
| Bv1 | S02,12’30.8’’ | E30,03’59.2’’ | Kv1 | S02,06’18.4’’ | E29,48’16.1’’ |
| Bv2 | S02,11’53.3’’ | E30,04’13.1’’ | Kv2 | S02,05’18.4’’ | E29,49’03.8’’ |
| Bv3 | S02,13’042’’ | E30,03’52.9’’ | Kv3 | S02,05’16.1’’ | E29,49’06.0’’ |
| Bv4 | S02,13’08.0’’ | E30,04’01.8’’ | Kv4 | S02,06’31.8’’ | E29,48’27.4’’ |

Appendix 2 Currently soybean varieties cultivated in Rwanda

| *Variety name* | *Grain colour* | *Flower colour* | *Maturing period (days)* | *Suitable area* | *Yield (kg/ha)* |
|---|---|---|---|---|---|
| Peka 6 | Yellow | White | 115 | Middle and lower lands | 2200 |
| Bossier | Yellow | Purple | 115 | Middle and lower lands | 2200 |
| Ogden | Yellow- green | Purple | 110 | Lower lands | 2000 |
| Duiker | Yellow | White | 117 | Middle lands | 2400 |
| 449/16 | Yellow | Purple | 117 | Middle lands | 2400 |
| Soprosoy | Yellow | Purple | 90 | Lower lands | 1800 |
| Yezumutima | Red burgundy | White | 100 | Lower lands | 2000 |
| Buki | Yellow | White | 115 | Middle and lower lands | 2200 |
| 1740-2E | Yellow | Purple | 115 | Middle and lower lands | 2200 |

Source: Soybean programme, ISAR

Appendix 3 Developmental stage of soybean

| *Stage* | *Description* | Data collected |
|---|---|---|
| V1 | Completely unrolled leaf at the unifoliolate node | |
| V2 | Completely unrolled leaf at the first node above the unifoliolate node | Farm selection, interviews at homes and field selection |
| V3 | Three nodes on main stem beginning with the unifoliolate node | Interviews about fields and crops management, soil sampling and GPS measurements |
| R1 | One flower at any node | |
| R2 | Flower at node immediately below the upper most nodes with a completely unrolled leaf. | |
| R3 | Pod 0.5 cm (1/4 inch) long at one of the four uppermost nodes with a completely unrolled leaf | |
| R4 | Pod 2 cm(3/4 inch) long at one of the four uppermost nodes with a completely unrolled leaf | Biomass for DM |
| R5 | Beans beginning to develop (can be felt when the pod is squeezed) at one of the four uppermost nodes with a completely unrolled leaf | |
| R6 | Pod containing full size green beans at one of the four uppermost nodes with a completely unrolled leaf | |
| R7 | Pod yellowing; 50% of leaves yellow. Physiological maturity | Fresh and dry grain and stover yields |
| R8 | 95% of pods brown. Harvest maturity. | Dry grain yield |

Source: Fehr W.R. et al., 1971

Appendix 4 Developmental stage of common bean

| Stage | [a] Description | Data collected |
|---|---|---|
| V0 | Germination: Water absorption by the seed, emergence of the radicle, and transformation into the primary root. | |
| V1 | Emergence: Cotyledons appear at soil level and begin to separate. The epicotyl initiates its development | |
| V2 | Primary leaves: Totally opened primary leaves | |
| V3 | First trifoliate leaf: The first trifoliate leaf opens and the second trifoliate leaf appears | |
| V4 | The third trifoliate leaf: The third trifoliate leaf opens and the buds on the lower nodes produce branches | Farm selection, interviews at homes and field selection<br>Interviews about fields and crops management, soil sampling and GPS measurements |
| R5 | Preflowering: The first flower bud or the first raceme appears. Flower buds in determinate varieties are formed on the last stem or branch node. In inderminate varieties racemes are first observed on the lower nodes. | |
| R6 | Flowering: the first flower opens | |
| R7 | Pod formation: The first pod appears being more than 2.5 cm long | Biomass for DM |
| R8 | Pod filling: The first pod begins to fill (seed growth). At the end of the stage the seeds lose their green color and begin to show varietal characteristics. Defoliation initiates. | Fresh and dry grain and stover yields |
| R9 | Physiological maturity: Pods lose their pigmentation and begin to dry. Seeds develop their typical varietal color. | |

Source: Van Schoonhoven and Pastor-Corrales, 1987).

[a] *Each stage begins when 50% of the plants show the conditions that correspond to the description*.

Appendix 5 Prices used for economic calculations

| | crop | Seeds | Grains or roots US$ kg$^{-1}$ | | | Chemical fertilizer | |
|---|---|---|---|---|---|---|---|
| | | | 2012 price | Average of lower price (2008-2011) | Average of highest price (2008-2011) | type | Price (US$ kg$^{-1}$) |
| *Bugesera* | soybean | 0.66 | 0.62 | 0.45 | 0.56 | DAP | 1 |
| | maize | 0.41 | 0.25 | 0.17 | 0.22 | Urea | 0.8 |
| | beans | 0.66 | 0.39 | 0.18 | 0.21 | | |
| | cassava | 0.00 | 0.22 | NA | NA | | |
| | groundnuts | 1.98 | 1.82 | 1.24 | 1.61 | | |
| *Kamonyi* | soya | 0.74 | 0.66 | 0.50 | 0.64 | | |
| | maize | 0.41 | 0.50 | 0.31 | 0.44 | | |
| | beans | 0.66 | 0.51 | 0.09 | 0.17 | | |
| | cassava | 0.00 | 0.21 | NA | NA | | |
| | groundnuts | 1.98 | 1.82 | 1.24 | 1.61 | | |

*NA= not available*

Appendix 6 Protein and energy content

| Crop | Protein (g/100 g) | Protein (g/1000 g) | Energy (Kcal/100g) | Energy (Kcal/1000g) |
|---|---|---|---|---|
| Beans | 23 | 230 | 336 | 3360 |
| Cassava | 1.5 | 15 | 340 | 3400 |
| Groundnuts | 23.2 | 232 | 549 | 5490 |
| Maize | 9.4 | 94 | 357 | 3570 |
| Sorghum | 10.7 | 107 | 345 | 3450 |
| Soybean | 33.7 | 337 | 405 | 4050 |

**Source:** http://www.fao.org/docrep/w0078e/w0078e06.htm

Appendix 7. Measure N concentration in soybean and beans

| Bugesera | | | | | Kamonyi | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Farm ID | Legume | Field | Sample type | Total N % | Farm ID | Legume | Field | Sample type | Total N % |
| BP1 | soya | Field A | Grain | 5.4 | KP1 | bean | Field A | Grain | 3.1 |
| BP1 | soya | Field A | Stover | 0.7 | KP1 | bean | Field A | Stover | 1.2 |
| BP1 | soya | Field B | Stover | 0.6 | KP1 | bean | Field B | Grain | 3.4 |
| BP1 | bean | Field C | Grain | 3.6 | KP1 | bean | Field B | Stover | 1.5 |
| BP1 | bean | Field C | Stover | 1.2 | KP1 | soya | Field C | Grain | 5.9 |
| BP2 | soya | Field A | Grain | 5.7 | KP1 | soya | Field C | Stover | 0.6 |
| BP2 | soya | Field A | Stover | 0.7 | KP2 | bean | Field A | Grain | 3.1 |
| BP2 | bean | Field B | Grain | 4.1 | KP2 | bean | Field A | Stover | 1.3 |
| BP2 | bean | Field B | Stover | 1.0 | KP2 | bean | Field B | Grain | 3.5 |
| BP2 | bean | Field C | Grain | 4.1 | KP2 | bean | Field B | Stover | 1.3 |
| BP2 | bean | Field C | Stover | 1.4 | KP2 | soya | Field C | Stover | 0.8 |
| BP3 | bean | Field A | Grain | 3.8 | KP3 | bean | Field A | Grain | 3.1 |
| BP3 | bean | Field A | Stover | 1.5 | KP3 | bean | Field B | Grain | 3.9 |
| BP3 | bean | Field B | Grain | 3.5 | KP3 | bean | Field B | Stover | 1.3 |
| BP3 | bean | Field B | Stover | 1.4 | KP3 | soya | Field C | Grain | 6.8 |
| BP3 | soya | Field C | Grain | 5.8 | KP3 | soya | Field C | Stover | 0.9 |
| BP3 | soya | Field C | Stover | 0.6 | KP4 | bean | Field A | Grain | 3.4 |
| BP4 | bean | Field A | Grain | 3.2 | KP4 | soya | Field B | Grain | 6.6 |
| BP4 | bean | Field A | Stover | 1.3 | KP4 | soya | Field B | Stover | 0.8 |
| BP4 | bean | Field B | Grain | 5.8 | KP4 | soya | Field C | Grain | 6.1 |
| BP4 | bean | Field B | Stover | 0.6 | KP4 | soya | Field C | Stover | 1.0 |
| BP4 | soya | Field C | Grain | 3.7 | KR1 | bean | Field A | Grain | 3.7 |
| BP4 | soya | Field C | Stover | 0.6 | KR1 | bean | Field A | Stover | 1.2 |
| BR1 | bean | Field A | Grain | 3.5 | KR1 | soya | Field B | Grain | 6.6 |
| BR1 | bean | Field A | Stover | 0.9 | KR1 | soya | Field C | Grain | 6.3 |
| BR1 | soya | Field B | Grain | 6.6 | KR1 | soya | Field C | Stover | 0.9 |
| BR1 | soya | Field B | Stover | 1.1 | KR2 | soya | Field B | Grain | 6.1 |
| BR1 | bean | Field C | Grain | 3.4 | KR2 | soya | Field C | Grain | 6.2 |
| BR1 | bean | Field C | Stover | 1.2 | KR2 | soya | Field C | Stover | 1.2 |
| BR2 | soya | Field A | Grain | 6.2 | KR3 | bean | Field A | Grain | 3.4 |

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|---|---|---|---|---|---|---|---|---|---|
| BR2 | soya | Field A | Stover | 0.6 | KR3 | bean | Field A | Stover | 1.1 |
| BR2 | bean | Field B | Grain | 3.0 | KR3 | bean | Field B | Grain | 3.3 |
| BR2 | bean | Field B | Stover | 1.5 | KR3 | bean | Field B | Stover | 1.7 |
| BR2 | bean | Field C | Grain | 3.4 | KR3 | soya | Field C | Grain | 5.6 |
| BR2 | bean | Field C | Stover | 1.2 | KR3 | soya | Field C | Stover | 0.5 |
| BR3 | bean | Field A | Grain | 3.5 | KR4 | bean | Field A | Grain | 3.7 |
| BR3 | bean | Field A | Stover | 1.5 | KR4 | bean | Field A | Stover | 2.1 |
| BR3 | soya | Field C | Grain | 6.7 | KR4 | soya | Field C | Grain | 6.3 |
| BR3 | soya | Field C | Stover | 0.6 | KR4 | soya | Field C | Stover | 1.0 |
| BR4 | bean | Field A | Grain | 3.2 | KV1 | bean | Field A | Grain | 3.7 |
| BR4 | bean | Field A | Stover | 1.1 | KV1 | bean | Field A | Stover | 0.8 |
| BR4 | soya | Field B | Grain | 6.3 | KV1 | bean | Field B | Grain | 3.3 |
| BR4 | soya | Field B | Stover | 0.9 | KV1 | bean | Field B | Stover | 1.4 |
| BR4 | bean | Field C | Grain | 3.6 | KV1 | soya | Field C | Grain | 6.2 |
| BR4 | bean | Field C | Stover | 2.0 | KV1 | soya | Field C | Stover | 1.0 |
| BV1 | soya | Field A | Grain | 5.7 | KV2 | bean | Field A | Stover | 1.0 |
| BV1 | soya | Field A | Stover | 1.2 | KV2 | bean | Field B | Grain | 3.3 |
| BV1 | bean | Field C | Grain | 3.3 | KV2 | bean | Field B | Stover | 1.2 |
| BV1 | bean | Field C | Stover | 1.0 | KV2 | soya | Field C | Grain | 6.3 |
| BV2 | soya | Field A | Grain | 5.3 | KV2 | soya | Field C | Stover | 1.0 |
| BV2 | soya | Field A | Stover | 0.5 | KV3 | bean | Field A | Grain | 3.2 |
| BV2 | bean | Field B | Grain | 3.7 | KV3 | bean | Field A | Stover | 1.4 |
| BV2 | bean | Field B | Stover | 1.3 | KV3 | bean | Field B | Grain | 3.4 |
| BV2 | bean | Field C | Grain | 3.3 | KV3 | bean | Field B | Stover | 1.4 |
| BV2 | bean | Field C | Stover | 1.5 | KV3 | soya | Field C | Grain | 6.0 |
| BV3 | bean | Field A | Grain | 3.7 | KV3 | soya | Field C | Stover | 0.7 |
| BV3 | bean | Field B | Grain | 5.9 | KV4 | bean | Field A | Grain | 3.3 |
| BV3 | bean | Field B | Stover | 0.7 | KV4 | bean | Field A | Stover | 1.4 |
| BV3 | soya | Field C | Grain | 3.3 | KV4 | soya | Field B | Grain | 6.9 |
| BV3 | soya | Field C | Stover | 1.1 | KV4 | soya | Field B | Stover | 0.9 |
| BV4 | bean | Field A | Grain | 3.5 | KV4 | soya | Field C | Grain | 6.3 |
| BV4 | bean | Field A | Stover | 0.8 | KV4 | soya | Field C | Stover | 1.3 |
| BV4 | soya | Field B | Grain | 6.6 | KW1 | bean | Field A | Grain | 3.6 |
| BV4 | soya | Field B | Stover | 1.7 | KW1 | bean | Field A | Stover | 1.7 |

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|---|---|---|---|---|---|---|---|---|---|
| BV4 | bean | Field C | Grain | 3.6 | KW1 | soya | Field B | Grain | 5.8 |
| BV4 | bean | Field C | Stover | 1.4 | KW1 | soya | Field B | Stover | 1.0 |
| BW1 | soya | Field A | Grain | 6.9 | KW1 | soya | Field C | Grain | 6.1 |
| BW1 | soya | Field A | Stover | 0.7 | KW1 | soya | Field C | Stover | 0.8 |
| BW1 | bean | Field B | Grain | 3.0 | KW2 | bean | Field A | Grain | 3.1 |
| BW1 | bean | Field B | Stover | 1.1 | KW2 | bean | Field A | Stover | 0.9 |
| BW1 | bean | Field C | Grain | 2.9 | KW2 | soya | Field B | Stover | 0.7 |
| BW1 | bean | Field C | Stover | 1.5 | KW2 | soya | Field C | Stover | 0.7 |
| BW2 | bean | Field A | Grain | 3.5 | KW3 | bean | Field A | Grain | 3.5 |
| BW2 | soya | Field B | Grain | 6.8 | KW3 | bean | Field A | Stover | 1.3 |
| BW2 | bean | Field C | Grain | 3.3 | KW3 | soya | Field B | Stover | 0.7 |
| BW2 | bean | Field C | Stover | 1.3 | KW3 | soya | Field C | Grain | 6.8 |
| BW3 | bean | Field A | Grain | 3.3 | KW3 | soya | Field C | Stover | 0.6 |
| BW3 | bean | Field A | Stover | 1.0 | KW4 | bean | Field A | Grain | 3.8 |
| BW3 | soya | Field B | Grain | 4.8 | KW4 | bean | Field A | Stover | 1.5 |
| BW3 | soya | Field B | Stover | 1.2 | KW4 | soya | Field B | Grain | 6.4 |
| BW3 | bean | Field C | Grain | 3.6 | KW4 | soya | Field B | Stover | 1.2 |
| BW3 | bean | Field C | Stover | 1.2 | KW4 | soya | Field C | Grain | 4.5 |
| BW4 | bean | Field A | Grain | 4.0 | KW4 | soya | Field C | Stover | 0.5 |
| BW4 | bean | Field A | Stover | 1.0 | | | | | |
| BW4 | soya | Field B | Grain | 3.2 | | | | | |
| BW4 | bean | Field C | Grain | 5.0 | | | | | |
| BW4 | bean | Field C | Stover | 0.6 | | | | | |