Characterisation of Bean Farming Systems Across Farm Types in Northern and Eastern Rwanda

Identification of Potential Niches for Legume Technologies

Moritz Reckling
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Abstract

N_2AFRICA is a development and research project focused on putting nitrogen fixation to work for smallholder farmers growing legume crops in Africa. Within this project, bean (*Phaseolus vulgaris* L.) farming systems in Northern and Eastern Rwanda were characterised and potential niches for grain legume technologies explored. Data were collected on resource flows, soil properties, crop productivity, field management, and biological nitrogen fixation (BNF) and on farmers assessment of production constraints. Farmers were classified according to regional specific resource endowment indicators, following the governmental household typology 'Ubudehe'. Resource-poor farmers are permanently food insecure and are mainly constrained by land, labour, and inputs and achieve relatively low climbing bean yields of 1.18 Mg ha^{-1}. Resource-rich farmers are food secure and have the capital to hire labour and rent land due to their market orientation and off-farm activities. Such farmers achieve average climbing bean grain yields of 2.27 Mg ha^{-1}. BNF measured with the natural abundance method was relatively low with on average 50% N derived from the atmosphere and 93 kg N ha^{-1} fixed in all above- and belowground plant parts. Depending on farmers' bean residue management, N-budgets per field ranged from -80 to 45 kg N ha^{-1} neglecting N returned to fields in animal manure after feeding bean residues. Resource-poor farmers, who all fed bean residues to animals, had an average negative N-budget of -43 kg N ha^{-1}. Wealthier farmers, who retained part of the residues on fields, had an average N budget of -3 kg N ha^{-1}. No evidence could be found that field distance from the homesteads influences soil fertility. Total N, organic C, and sand fraction are influenced by inherent factors (landscape) and do not correlate with bean grain yield. On the contrary, available P, and exchangeable Mg, Ca, and CEC correlate with grain yield and do not seem to be influenced by landscape. Beans play currently a major role in the farming systems in both sites. In Burera, climbing beans fit into a niche due to favourable agro-ecological, social, and economical factors. In Bugesera, recent droughts discouraged farmers to grow beans, but made groundnut, which is a more drought tolerant crop with high economic value, more popular.. This study shows that potential niches for legume technologies are site and farm type dependent. An increase in the area under climbing beans is not likely and opportunities for an increase in productivity and BNF are likely to be a better availability of quality stakes and higher application rates of organic manure. To achieve positive partial N-budgets on fields of resource-poor farmers, in addition an increased availability of alternative animal feed sources would be needed to reduce the losses of nitrogen in bean residues that are currently used as feed (because little manure is retuned). The limitation of stakes possibly also limits other technological improvements, including improved varieties, mineral fertilisers etc. especially in the case of the resource-poor farmers. From the provision of high yielding varieties, currently mainly resource-rich farmers profit since resource-poor do not keep the seed and have no long-term access to such varieties. Different bean variety preferences of farmers need to be taken into account, including varieties suitable for harvesting immature plant parts (pots and leaves). In Bugesera, strategies need to be implemented to stop the reductions of bean-cultivated area, the current decline in soybean cultivation and to further stimulate the already increasing cultivation of groundnut. Such strategies should include the promotion of drought tolerant bean varieties. The study highlights the complexity of smallholder farming systems in East/Central Africa and bean farming related trade-offs e.g. for bean residue management. This underlines the importance of studies on the farm rather than the single plot scale. Further, it shows that the 'Ubudehe' farm typology is useful to explain variations in resource use and productivity and is a potential tool for tailoring extension and technology services to the needs of farmers.

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1. Introduction

N_2AFRICA is a development and research project focused on putting nitrogen fixation to work for smallholder farmers growing legume crops in Africa. The rationale of N_2AFRICA is to raise grain legumes yields, increase biological nitrogen fixation (BNF), and increase household income of smallholder farmers. Within this project, farming systems in Northern and Eastern Rwanda were characterised with a focus on common beans (*Phaseolus vulgaris* L.) and potential niches for grain legume technologies explored.

In Rwanda, and other countries in East and Central Africa, common beans play a major role in farming systems due to a high consumption in the household, a high marketing potential and serving as valuable feed for livestock.

In Rwanda, a nationwide survey conducted by ISAR and CIAT found that 86% of farmers grow common beans, bush beans in low altitude zones and climbing beans high altitude zones. Rwandan households have among the highest per capita bean consumption in the world of 38 kg $capita^{-1}$ $year^{-1}$. Around 75% of the households have to buy beans to supplement their own production and 30% of the very poor eat bought beans on more than half of the days (CIAT 2008). This data highlights the extent of the bean deficit in Rwanda and calls for strategies to enable farmers in being more food sufficient.

Besides that, beans and other grain legumes are considered to have the potential to fulfil multiple purposes by serving as protein rich food and feed, and increasing soil fertility. Therefore, beans and other grain legumes currently receive much attention from development and research programs (including N_2AFRICA) promoting intensification of production among smallholder farmers in sub-Saharan Africa.

Detailed information on the current farmers' production practises, actual yields, and constraints are still insufficient. Besides, it remains unclear if farming practises and productivity differ across farm types with different resource endowment. Especially the productivity, BNF, and N-budgets of climbing beans have not yet been investigated under farmers' management conditions, and to clarify whether N inputs from fixation lead to a net gain or drain of total N.

Filling this knowledge gap is urgently needed as an *ex-ante* assessment for bean supporting programmes, specifically N_2AFRICA, in order to allocate 'best fit' extension and technological services to farmers.

Framework and Research Question

This study therefore explores the current role of bush and climbing beans in farmers' production systems and their farming practises. Besides, the research highlights the productivity and BNF performance of climbing beans in Northern Rwanda.

The study follows the Nutrient Use in Animal and Cropping systems – Efficiencies and Scales (NUANCES) framework and applies tools developed for detailed farming system characterisations within N_2AFRICA (based on the NUANCES approach). The framework can be used to assess changing agricultural systems with a focus on processes taking place at the farm rather than the field scale and is built on the four steps: Describe, explain, explore and design (Giller et al. 2011). It proves an adequate framework for this study because it provides tools to describe current bean production systems and their constraints on a farm scale. It further guides to explain the variability of resource allocation across farm types and allows to explore niches for an intensified bean cultivation and to design possible interventions using legume technologies.

The governmental household typology Ubudehe is used to stratify farmers across different farm types. This typology has so far not been used to study the variability of farming practises and performance across farming households. Since the Ubudehe is widely known by Rwandan stakeholders involved in agricultural policymaking, research based on this typology can be easily communicated and might lead to have a stronger impact.

To take different agro-ecological potentials and market access into account, this study focuses on two contrasting regions in Northern (Burera) and South-Eastern (Bugesera) Rwanda.

To address the above raised issues the following four research questions will be answered.

1. What is the role of beans in the farming systems and what are current bean farming practises in the two study sites, as influenced by farm and field types?
2. Can the Ubudehe household typology be used as a farm typology?
3. How productive are climbing beans (in Northern Rwanda) in farmers’ fields and how much nitrogen do they fix? Which factors influence the productivity and nitrogen fixation?
4. Where are niches for intensified bean cultivation for the different farm types?

2. Methodology

2.1 Research Location

This research was conducted in the two contrasting locations; Burera in the Buberuka highlands in Northern Rwanda, and Bugesera in the Savannah zone of the South-East (compare Figure 1).

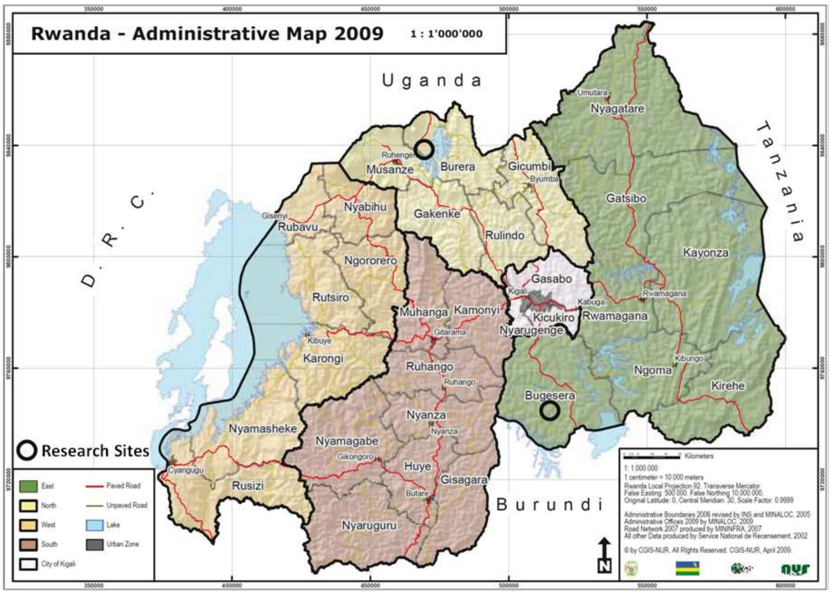


Figure 1. Administrative divisions of Rwanda and the two research sites (REMA 2009)

The two study sites were selected according to their contrasting nature representing the extremes in terms of agro-ecological and socio-economic potential.

Burera is densely populated with 671 people km^{-2} and is agro-ecologically favoured by a high and well-distributed annual precipitation of on average 1500 mm and relatively fertile soils from young volcanic origin (Table 1). Population density in Bugesera is 205 people km^{-2} and mean annual precipitation is much lower with 800 mm. The area is at risk of severe droughts (REMA 2009).

Main grain legumes cultivated are climbing beans in Burera and bush beans, groundnut and soybean in Bugesera.

Table 1. Population density and precipitation of both study sites and the national average

Study site	Population density in 2002 (people km^{-2})	Mean annual precipitation (1950-2005) (mm)
Burera	671	1500
Bugesera	205	800
National average	321	1250

(PEI 2007 and REMA 2009)

2.2 Farm Sampling

2.2.1 The Household Typology 'Ubudehe'

Individual farms studied in detail were selected according to the governmental typology of Rwandan households, called Ubudehe. The Ubudehe (translated: local collective action) is a program of the Ministry of Local Governments (MINALOC) and the Rwandan Common Development Fund (CDF), which was launched in 2001 (compare Ansoms 2008). It aims at targeting poverty alleviation, and has a main component of stratifying households according to their resource status (this enables poverty alleviation programs to target households of different resource status e.g. the 'one farm one cow' policy targets only very resource poor households and besides, the Ubudehe provides more power to local authorities and increases decentralisation).

For a homogenous categorisation, the Rwandan government defined six household categories. To refine and adapt the general characteristics locally, the local governments of each cell determines cell specific resource endowment indicators. In a village meeting with all citizens, the Ubudehe committee classifies each household into one of the six categories. Therefore, categories are the same country wide, but indicators for the categorisation vary from one cell to another. This research concentrates on four Ubudehe categories and considers them as separate household types.

2.2.2 Farm Selection and Rapid Farm Characterisation

Within Burera and Bugesera district, one representative cell (in terms of environmental and farming characteristics) was selected. In the cells, three households from each of the four identified types out of the local government documentation were randomly selected as case study farms for detailed characterisation such that three samples per farm type were evenly spatially distributed over the entire cell (Figure 2). All fields of the selected farms were included (except a couple that were not accessible) irrespective of the distance from the homestead (Figure 2).

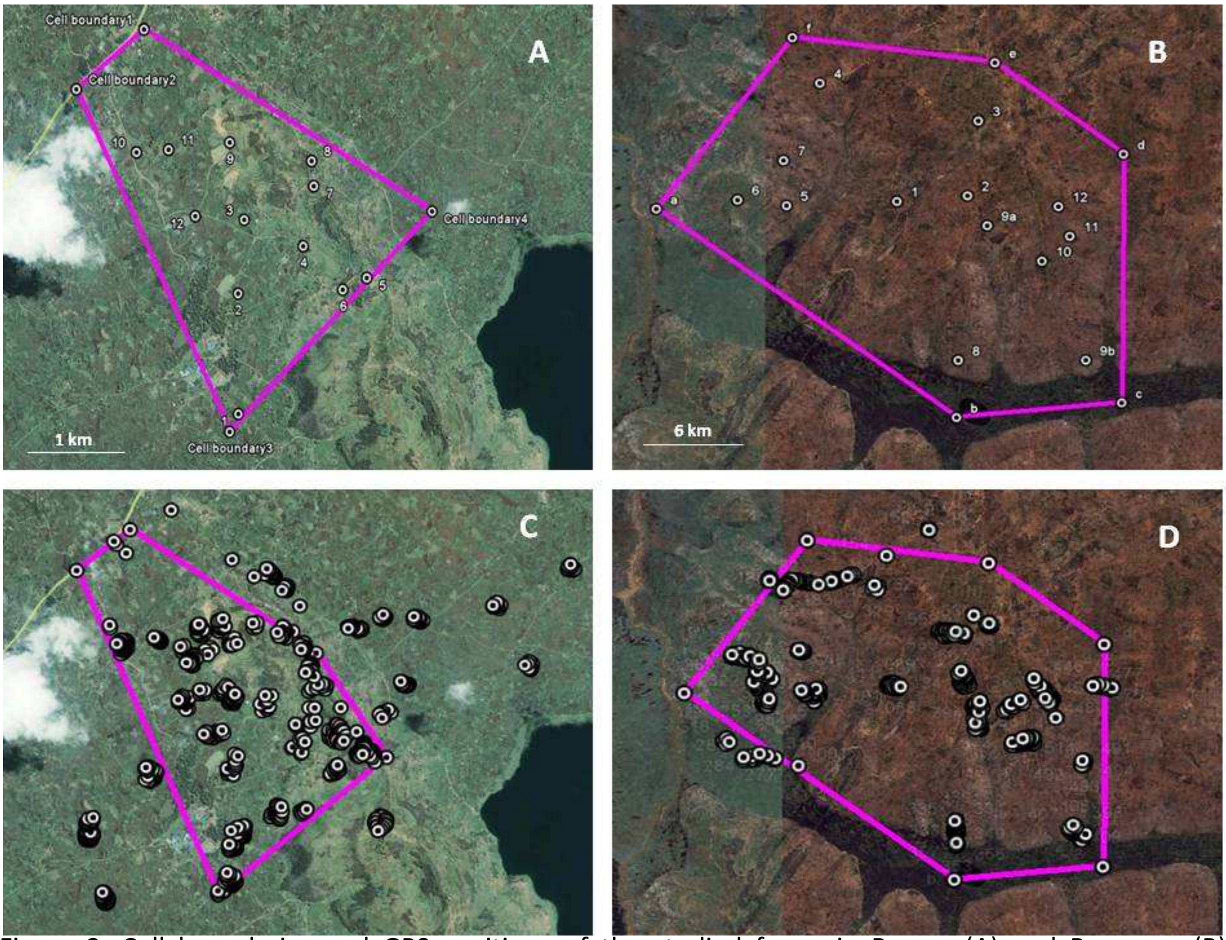


Figure 2. Cell boundaries and GPS positions of the studied farms in Burera (A) and Bugesera (B) and positions of the studied fields in Burera (C) and Bugesera (D)

The categories assigned by the government were verified through a rapid farm characterisation. This included the following aspects: family composition, membership in associations, farm size, number of livestock, housing conditions, education, means of communication, access to credits, off-farm income, hiring/selling of labour, means of transport, status of medical care and food security.

The rapid farm characterisation confirmed the government categorisation although some characteristics of few households did not all fit into one type e.g. a household owned a cow although farmers of that type normally do not keep cattle, they could still be classified since most characteristics fit and the general impression of the homestead and farm confirmed the classification.

2.3 Detailed Farming Systems Characterisation

The research procedure was carried out in three major steps of data collection (compare Figure 3). The first step was the interview at the farmers homestead about the farming system and resource allocation on the farm scale. The second step was an interview on the farmers' fields on the management on the field scale and the third step were the field measurements (soil samples etc.).

1st step: Interview 2nd step: Field visit 3rd step: Measurements

Figure 3: The three step data collection procedure in this research

2.3.1 Interview

All interviews were semi-structured using a pre-defined protocol with quantitative and qualitative questions and answer options (compare Annex 1). The interviews were held in French (Burera) and English (Bugesera) with the help of an interpreter to translate into Kinyarwanda. In the beginning of the interview, a discussion was stimulated about the farmers' farm components e.g. the livestock. In this case, he or she was asked to explain how many animals he or she has, the purpose of keeping them, the origin and type of feed etc. If questions of the protocol had not been answered after this general explanation these were asked specifically. Therefore, questions did not strictly follow the order of the protocol and left room to issues and explanations that were not part of the protocol.

In Burera, the interpreter was a local agronomist and knows all studied households well. He was involved in the whole study including the selection of farmers. These had trust in him and were very open to explain their farming strategies and constraints in detail. In Bugesera, the first interpreter was the governmental agronomist of the sector who was involved in selecting the studied farms and the rapid characterisation. He was respected as an authority, which helped to legitimise the study. The interpreter for the rest of the study was a young agricultural student, who did not know the study site very well.

The interview at the farmers' homesteads included a discussion about general farm characteristics, including the cropping history, livestock (including manure and feed management), marketing, expenditures on labour and farming inputs, off-farm income. The interview had a strong focus on bean production: benefits to grow beans, importance compared with other crops, constraints, possibilities to expand the production, perception of a good bean variety and observations on rotational effects.

2.3.2 Field Visit

The second interview was carried out on the individual fields of the farmer to assess the field and management characteristics of four cropping seasons (two years). The topics included:

- Ownership of the field
- Type and variety of the crop (and intercrop)
- Crop rotation
- Type of inputs used, the timing of application and the input source
- Minimum and maximum yields
- Proportions of the produce consumed, sold and kept as seed
- Proportions of crop residues left in the field and collected as feed or for other purposes
- Scoring of soil fertility status (very fertile, fertile, poor and very poor)
- Management activities (labour days per activity and hired/family labour)

2.3.2 Measurements

Field sizes of all fields (except a couple which could not be accessed) were measured by collecting waypoints (coordinates) of all field corners and curves, using a Garmin eTrex Venture® HC GPS device with an accuracy of 3-4 meters. Fields smaller than 20 x 20 meters were additionally measured using a tape. Waypoints were processed with the Garmin MapSource software to generate the field and distances to the homesteads (neglecting curves in paths and differences in altitudes). Besides, soil type, slope, stage of visible erosion, and drainage were classified.

Soil samples of all fields with beans and other major crops were collected (96 in total). In a 'Z shape', 10 to 15 samples were taken per field in 0-20 cm depth using an auger. Ten samples were taken on small and homogenous and 15 on very big and heterogeneous fields. Samples were combined to one composite sample of 0.4-0.8 kg. In Bugesera, on very sandy soils with high gravel content and on peat soils in the swamps, samples needed to be collected by hand (by digging holes of 0-20 cm depth).

<u>2.4 Quantifying Climbing Bean Productivity and BNF in Burera</u>

Climbing bean productivity was assessed through various tools: Farmers' estimations, above ground biomass harvesting and measurements of dry and fresh grain yields. Measurements were carried out at different developmental stages of the bean crop. These are indicated according to the CIAT classification (Table 2) comprising of 5 vegetative (V0-V4) and 5 reproductive (R5-R9) stages.

Stake quality and quantity in all climbing bean fields were assessed by counting the number of stakes on a representative 10 m^2 area and by measuring the average, minimum and maximum height. Besides, the material of the stakes was estimated according to the proportion of wood species (neglecting differences in species), Pennisetum (*Pennisetum purpureum* Schum) and Ricinus (*Ricinus communis* L.).

Table 2. Developmental stages of the common bean plant

Stage	Description[a]	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 trifoliolate leaf: The first trifoliolate leaf opens and the second appears	-
V4	Third trifoliolate leaf: The third trifoliolate opens and the buds on the lower nodes produce branches.	Farm selection and interviews at the homes
R5	Pre-flowering: The first flower bud or raceme appears. In indeterminate varieties racemes are first observed on the lower nodes.	Field interviews, stake assessment, soil samples, GPS measurements
R6	Flowering: The first flower opens.	-
R7	Pod formation: The first pod appears being more than 2.5 cm long.	Biomass for DM and BNF (R7 and early R8)
R8	Pod filling: The first pod begins to fill (seed growth). At the end of the stage the seeds lose their green colour and begin to show varietal characteristics. Defoliation initiates.	Fresh grain and pod yield (late R7 and R8)
R9	Physiological maturity: Pods lose their pigmentation and begin to dry. Seeds develop their typical varietal colour.	Dry grain yield

[a] Each stage begins when 50% of the plants show the conditions that correspond to the description (Van Schoonhoven and Pastor-Corrales 1987).

2.4.2 Yield and Above Ground Biomass Assessment

Farmers measured and recorded their daily fresh bean harvest separate per field with provided scales and facilitation by the local agronomist.

Yields of dry grains were kept separately by farmers per field (in different bags) and measured at the end of the growing season by the local agronomist.

Forty-six climbing bean above ground biomass samples from 23 selected fields were collected at 85-100 days after sowing. Since climbing beans are non-determinate, pod maturity varies at one plant with non-filled pods at the top of the plant and filled pods on the bottom.

To achieve one representative sample per bean field, two randomly selected areas of 1-3 m^2 were harvested. In October, the areas for biomass collection were selected and fenced with a simple rope to prevent people from harvesting fresh leaves and green pods. The fenced area included a buffer of 0.5 m and was placed not on the border rows and on a representative spot of the field taking into account the size of stakes, planting density and the relief. From each of these sites, GPS coordinates; the number and height of stakes, and were recorded.

Since climbing bean plants climb uncontrollably to neighbouring stakes outside the measured site and at the same time from other origins inside the site, all plant tissue inside the boundaries was harvested by cutting the first node above ground.

Total above ground bean biomass, including shed dry leaves was weighed. Pods were separated from the stover and weighed separately. From both, stover and pods a composite sub-sample was taken after careful mixing and quartering.

All fresh weights were obtained directly after harvesting in the field using a precise digital scale. After the sub-samples were packaged, the remaining plant material was given to the farmer as food, feed and for mulching. Farmers were compensated for the harvested bean plants according to the estimated value.

2.4.3 Reference Plants for ^{15}N analysis

Reference plants for ^{15}N analysis were collected at the same time as the biomass harvesting. Forty-six composite reference plant samples of non-leguminous dicotyledonous weeds growing within a 2 m radius of the biomass collection site were collected. For each site three to five different weed species (compare Table 3) were collected and mixed to a composite sample of 150 g.

Table 3. Botanical names of collected weed species as reference plants for ^{15}N analysis

Botanical name	Family name	Frequency collected
Galinsoga parviflora Cav.	Asteraceae	46
Persicaria nepalensis (Meisn.) H. Gross	Polygonaceae	45
Bidens pilosa L.	Asteraceae	26
Ageratum conyzoides L.	Asteraceae	17
Bothriocline ugandensis (Moore) Gilbert	Asteraceae	13
Crassocephalum vitellinum (Benth.) S. Moore	Asteraceae	11
Tagetes minuta L.	Asteraceae	11
Achyrantes aspera L.	Amaranthaceae	3
Crassocephalum rubens (Jacq.) S. Moore	Asteraceae	5

2.4.4 Nodulation Scoring

After biomass harvesting, four to eight climbing bean roots were carefully dug up and the amount of vital nodules were scored with a scoring scheme from 0 to 5 (compare Table 4). Nodule vitality was checked by assessing the tissue colour inside the nodule. Reddish colours indicated vitality and active fixation (Bala et al. 2010).

The scoring scheme applied in this research was altered from Bala et al. (2010) who developed a scheme for soy bean nodules. This scheme was tested and found not practical for climbing beans, because the number of nodules were much higher in climbing beans and the division between two layers (as suggested by Bala et al.) of 0-5 cm and <5 cm did not seem useful. The scheme was altered by increasing the number of nodules per score and considering the rooting depth of 0-15 cm.

Table 4. Scoring scheme for nodules in climbing beans (Adapted from Bala et al. 2010)

Score	0	1	2	3	4	5
Number of estimated nodules	0	<10	10-20	20-30	30-50	>50

2.5 Soil and Plant Analysis

Soil samples were air-dried and sieved to 2 mm for analysis. The 'Crop Nutrition Laboratory Services' in Nairobi (Kenya) analysed pH (H_2O), available P (Bray), CEC, and exchangeable cations (K, Ca, Mg, Na). The laboratory of the Tropical Soil Biology and Fertility Institute (TSBF) in Nairobi, analysed soil particle size (PSA) and prepared samples for organic C and total N analysis by fine grinding. Organic C and total N analysis were carried out at KU Leuven (Belgium).

The dry matter (DM) content of climbing bean plants was analysed of the harvested pod and the shoot samples. These were oven dried at 70°C for 48 hours until constant weight and weighed at the laboratory of the Institut des Sciences Agronomiques du Rwanda (ISAR), Musanze station. Reference plants were dried together with the bean samples at 70°C for 48 hours.

To determine the proportion of legume N derived from N_2-fixation, the ^{15}N natural abundance method according to Unkovich et al. (2008) and Peoples et al. (1989) was applied. This method is based on the principle that: provided the ^{15}N enrichment ($\delta^{15}N$) of the plant-available soil N differs from atmospheric N_2, the %N from N_2-fixation can be determined.

A weighted average was used to calculate the N-fixation rate (%Ndfa) for the whole bean crop according to the following calculation:

$$\text{Weighted mean atom\% }^{15}\text{N} = \frac{(\text{shoot N*shoot atom\% }^{15}\text{N} + \text{pod N*pod atom\% }^{15}\text{N})}{(\text{shoot N} + \text{pod N})}$$

Atom% ^{15}N was converted into δ^{15}N using the following equation provided by Peoples et al. (1989):

$$\delta = \frac{1000*((\text{atom\% }^{15}\text{N})\text{ sample} - (\text{atom\% }^{15}\text{N})\text{ standard}))}{(\text{atom\% }^{15}\text{N})\text{ standard})}$$

Where the standard is: 0.3663

The %N from N_2-fixation was calculated using the equation by Unkovich et al. (2008):

$$\%\text{N from N}_2\text{-fixation} = \frac{100*(\delta\,^{15}\text{N}_{reference} - \delta\,^{15}\text{N}_{legume})}{(\delta\,^{15}\text{N}_{reference} - \text{B})}$$

$\delta\,^{15}N_{reference}$ is the ^{15}N natural abundance of the shoots of the non-N_2-fixing reference plant collected from the same spot as the beans and deriving its entire N from the soil N; $\delta\,^{15}N_{legume}$ is the ^{15}N natural abundance of the shoots and pods of the N_2-fixing legume plant; B is a correction for the isotopic fractionation during N^2-fixation (Unkovich et al. 2008). A 'B value' of -2.16 was used for this study, which is the average from three studies in Australia, Japan and France with common beans (Unkovich et al. 2008: 245).

For calculating N-budgets including below ground N-fixation, this was assumed to equal relative above ground fixation and that root N equals 33% of above ground plant N (Wichern et al. 2008).

Evaluation of N analysis

To verify if the measured total soil-derived N is plausible, the possible N supply from the soil was estimated for the soil depth studied (0-20 cm). This was done by assuming a bulk density of 1.3 Mg/m^3 (measured average by Siriri et al. (2005) in terraces of South-western Uganda) and a maximum N mineralization of 2% per year using the following calculation:

Possible N supply from soil = 10000 x0.2 x(1.3x1000)x(%N/100)x0.02

2.6 Economic and Nutritional Analysis

The partial budget analysis calculates expenses, crop value, and net benefits on a field scale for the season studied (2011A) for grain legume and other important crops of the two study areas. For climbing and bush beans, budgets are compared across farm types.

The expenses include hired labour costs and opportunity costs for family labour (calculating with the same costs per hour), costs for planting material, mineral fertilisers, and biocides and for stakes in climbing beans (including opportunity costs for stakes not purchased).

Calculations consider opportunity costs for family labour, stakes produced on-farm and seed kept for next season since this provides a better evaluation of the economic profitability. It is based on the assumption that farmers could work for others instead of their own farm and stakes grown on the own farm could be sold to other farmers. Farmers either buy or keep the planting material, the costs are assumed the same (although prices at the beginning of the season are higher and losses take place during storage). The amount of planting material used per ha was obtained from literature (Annex 2).

The crop value is derived from the marketable crop yield, not included are freshly harvested and consumed crop products such as leaves of beans, fresh maize etc. which often have an important food value. It is assumed that produce used for home consumption has the same value as produce sold on the market.

Prices used for the calculation of costs and crop value are based on prices in 2011, averaged and made uniform for both sites to allow comparisons across crops, farm types and sites (Annex 3).

Net benefit is calculated as the crop value after the expenses for crop production are deducted.

The calculation of energetic and protein inputs, is based on data from literature (Annex 4).

2.7 Statistical Methods

Comparisons at farm and field scale were calculated by subjecting the data to analysis of variance (ANOVA) and comparing means at a 5% LSD. For analysis on the farm scale, the balanced ANOVA was used. Due to an unequal number of fields across farms, the unbalanced ANOVA was used for calculations on the field scale. For correlations at the field scale, the Pearson correlation coefficient (r) was calculated assuming a linear relationship between variables and a normal distribution. Correlations were tested if statistically significant at $\alpha = 0.05$ using the one-tailed test.

3. Results

3.1 Farm Typology and Study site characterisation

Characteristics of Farm Types

The governmental categorisation of all households in the cells studied has been carried out in 2005 and revised in 2010. The distribution of all households is shown in Table 5, highlighting that category *Umukene* (poor) and *Umukene wifashije* (well-off) are the most common in both sites. Households belonging to the category *Umutindi nyakujya* (vulnerable) and Umukire (very rich) are excluded from this study because they are not involved in primary farming and hardly present.

Table 5. Characteristics of Ubudhe categories and their frequency in the study sites based on governmental statistics and data of the poverty reduction strategy (PRSP 2002: 15).

Ubudehe type	Farm type in this study	Household characteristics	No. of households per type (no.)	
			Gafuka cell (Burera)	Gicaca cell (Bugesera)
Umutindi nyakujya (vulnerable)	-	Beg to survive, have no land or livestock and lack shelter and food.	10	20
Umutindi (very poor)	1	Own very small land holdings, work for others to earn a living.	161	190
Umukene (poor)	2	Own little land, live on own labour and produce but have no surplus to sell and have no access to health care.	495	1159
Umukene wifashije (well-off)	3	Larger farmland, keep livestock, do not work for others and sell a surplus.	279	945
Umukungu (rich)	4	Educated, very large farm, keep cows, have off-farm income.	71	53
Umukire (very rich)	-	Have salaried jobs and are not primary involved in farming. Own a vehicle and big house.	2	0

Table 6 shows the characteristics of farm types in the two study sites. Farm Type 1 represents 16% and 8% of all households, is permanently food insecure and owns very little farm land of 0.06 ha and 0.42 ha on average, for Burera and Bugesera respectively. The land is not sufficient to produce food and therefore, farmers work permanently for others to be able to purchase food. In Bugesera, food quality is an issue because the diet is based on almost only cassava. Households have very few livestock, mainly sheep, goats and chicken. If they have a cow, then the government (through the 'one cow one farm' policy) donated it or they keep and feed cows from other farmers to get the milk and the second new offspring. They have small houses made of only local materials, no means of communication and their children attend school up to the primary level. This group receives support from the government, paying for full medical care of the whole household.

Table 6. Characteristics of farm types in the two study sites

Farm type	Av. farm size (ha)	No. of animals (no.)	Off-farm income	Use hired labour	Self sufficiency
Burera					
1	0.06	Max. 1 small livestock[a] or 1 cow donated[b]/on loan[c]	Work permanently for others	No	Insufficient, get support from government or church
2	0.34	Max. 1 cow on loan and 1-2 small livestock	Work occasionally for others	No	Partly insufficient
3	0.61	1-2 cows and 3-4 small livestock	None	Occasional	Sufficient and sell surplus
4	1.49	2-3 cows and 4-8 small livestock	Local bar, shop etc.	Permanent	Sufficient and sell surplus
Bugesera					
1	0.42	None to 5 small livestock (on loan)	None or work for others	No	Insufficient, get support from government or church
2	0.79	Max. 1 cow and 2-13 small livestock	Work for others	None to occasional	Sufficient to partly insufficient
3	0.89	Max. 4 cows and 7-11 small livestock	Hardly any	Occasional to permanent	Ssufficient and sell surplus
4	3.26	Max. 5 cows and 4-8 small livestock	Local bar, shop etc.	Permanent	Ssufficient and sell surplus

[a] Sheep, goats, chicken and rabbits; [b] Cow donated by the government through the 'one cow per farm' policy; [c] Cows are on loan from other farmers, they are fed and milked and the second offspring can be kept

Farm Type 2 is the most common type representing around 50% in both sites. Households own little farmland of 0.34 ha and 0.79 ha in Burera and Bugesera, respectively. In Burera, households are permanently food insecure and not self-sufficient. In Bugesera, the larger land sizes and off-farm income make them only partly food insecure and self-sufficient. Households have 1-2 and 2-13 small livestock in Burera and Bugesera, respectively and at maximum one cow, often on loan. Houses differ from those of farm Type 1 by their iron sheet roofing. In Bugesera, children attend secondary school and households have radios, a bank account, can pay for casual labour in the beginning of the season, and can pay for their medical care (health insurance). In Burera, household have less resources available than those in Bugesera, children attend mainly primary school, households have no radios, no bank accounts, use no casual labourers, and can hardly pay for medical care (no support from the government for this group). In both sites, household members work occasionally for others to earn money for food, school fees and other relevant items and services.

Farm Type 3 is considered 'well off' and the second most common farm type (27% and 40%), being food secure from own farm produce and able to sell a surplus on the market and pay for their own medical care. They own on average 0.61 ha and 0.89 ha land in Burera and Bugesera, respectively. Mean farmland in Bugesera is only slightly larger than for Type 2 but farming is more intensive and farmers in this class keep more livestock: 1-2 own cows and small livestock in Burera and none to four cows and small livestock in Bugesera. Households do not work for others and have no off-farm income at all in Burera and only little in Bugesera. All hire casual labour in the beginning of the season, have a bank account, radios, mobile phones and can send all children to secondary school and live in houses of better condition.

Farm Type 4 represents only 7% and 2.2% of households in Burera and Bugesera, with an average farm size of 1.49 ha and 3.26 ha, respectively. They employ permanent labour. All households keep cows (1-5) and many small livestock (5-8 heads), have houses plastered with cement, send their children to University, have radios, mobile phones and two bank accounts (one national and one for microfinance). They receive money from off-farm income through running local bars, banana beer making, shops, milling of corn, trade and other activities.

Characteristics of farm types in the two sites show general differences (compare Table 4). For livestock, chicken are less common (except for Type 4) but pigs more common in Burera than in Bugesera. In Bugesera maize and beans are cultivated on hired plots in swamps from associations (Farm Type 2, 3 and 4) in addition to hill-fields. Land sizes are bigger in Bugesera, due to a lower population density, and agricultural is still expanded. In Burera, land sizes per household gradually decrease due to population growth and buying land is extremely difficult.

Socio-economic Condition

Table 7 shows the socio-economic characteristics per farm and the two study sites in Burera and Bugesera. Gafuka cell, the study site in Burera comprises six villages, 1018 households, and a total population of 4884 people in 2010 with an average household size of 4.8 members. In 2005, the population was 4060 people, which highlights a high annual population growth of 3.4%, exceeding the countrywide growth rate of 2.7% (UN 2011). Current population density in Burera is among the highest in the country with 524 people km^{-2} (in 2010), exceeding the country's mean population density of 390 people km^{-2} (UN 2011). In the 2010 wealth assessment of households within the Ubudehe program, 65.4% of the population was classified as vulnerable, very poor and poor and 34.6 as well-off, rich and very rich (Local Government 2010).

Table 7. Average socio-economic data per farm for the two study sites Burera and Bugesera

Indicator	Burera	Bugesera
Farm structure		
Average farm size (ha)	0.88	1.71[b]
No. of fields	6.7	10.8
% of farm area rented	0	18
% farmland under common beans[a]	40	14
% farmland under grain legumes[a]	40	21
% that have livestock	100	67
No. of cows	1.6	2.4
No. of small livestock	2.5	5
Household and labour		
Household members	4.8	2.8
% that use only family labour	41	33
% that hire casual labour	33	33
% that hire permanent labour	25	33
Income		
% that work on other farms	33	25
% with additional income generating activities and sources	42	58
% that rely only on farm income	25	17

[a] over two seasons (2010B and 2011A), [b] including rented farmland

The study site in Bugesera, Gicaca cell, has a larger area and comprises 2367 households and 6686 people in 2010. Population growth between 2005 and 2010 was similar to Burera with 3.1%. Population density in 2006 was 248 people km^{-2} (MINAGRI/JICA 2007) and therefore below the country average. Bugesera is less populated because people migrated relatively recently (30-40 years ago) from more densely populated regions, e.g. from Gitarama and Burera. Total farm size is much larger although the size of families is smaller (2.8 household members) than in Burera. 57.8% of the population was classified as vulnerable, very poor and poor and 42.2 as well-off, rich and very rich (Local Government Bugesera 2010).

Comparing the farm structure between both sites, average farm size is not only much larger in Bugesera, single farmers also own more fields and rent on average 18% of their land from other farmers. Common beans are more widely grown in Burera, and although this is the only grain legume crop cultivated, their share of 40% of the total farmland is still higher than to that of all grain legumes cultivated in Bugesera together (21%). Although all farmers in Burera keep animals, the number of animals among those keeping them is higher in Bugesera. More family labour is used in Burera and less permanent labourers hired for farm activities. In Bugesera, more households have off-farm income compared with Burera, e.g. from beer making, trading, and owning shops (for the very rich).

Bio-physical Environment

Table 8 shows the bio-physical characteristics for the two study sites in Burera and Bugesera. The former lies within the agro-climatic zone of the volcanic highland plains (Cônes et hautes plaines volcaniques). Major soil types (FAO) are Mollic Andosols and on the hillsides, Humic Alisols originating from metamorphosis are present (Gent University/MINAGRI 2001). Based on own measurements, soils in Burera have higher silt and lower sand and clay content than soils in Bugesera. The fertility is higher in Burera shown by much higher mean concentrations of total N and organic C, although available P and exchangeable Ca are lower compared to soils in Bugesera. Mean annual rainfall is 1100 mm (Figure 4) in the recorded years from 1970 to 1992. The variation between years is 890 mm (1975) to 1400 (1972). In a typical year (1992), highest rainfall events occur during the two growing seasons (Figure 4, B), season A from September to December and season B from February to Mai.

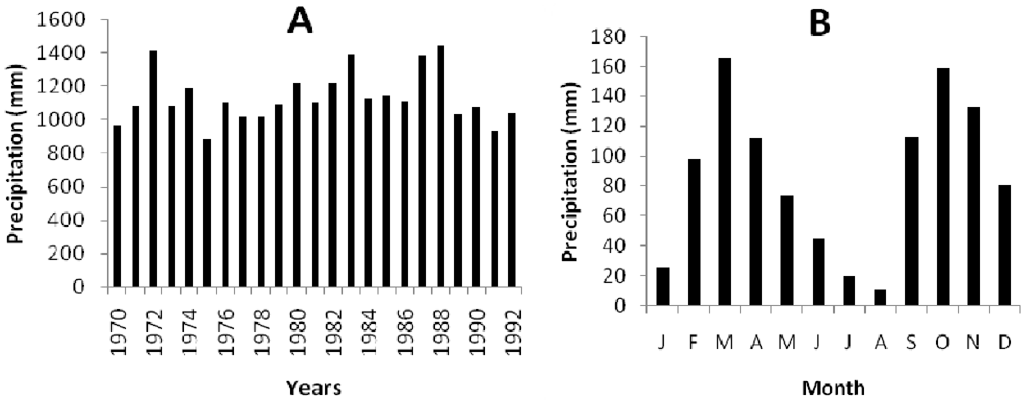


Figure 4. Total Annual precipitation recorded at ISAR weather station within the studied cell in Burera from 1970 to 1992; A total rainfall per year (mm) and B rainfall per month (mm) for the year 1992.

The study site in Bugesera is located in the agro-climatic zone of the eastern savannah of central Bugesera (Savanes de l'Est et du Bugesera Central). The region consists of a wide range of soil types due to the heterogeneity in topography and soil formation processes. Major soil types (FAO) are Xanthic and Humic Ferralsols originating from sedimentation or metamorphosis on hillsides and hilltops, and Haplic Acrisols of magmatic origin in valleys. Cultivated swamps are Mollic Gleysols with an alluvial origin (Gent University/MINAGRI 2001).

Land use in Bugesera changed over the last decades. Extensive savannas and their drought resistant shrubs have historically provided grazing lands for pastoralists who were probably the first inhabitants of the region. With increasing population densities, most of the natural vegetation (wetlands, forest savannah and woodlands) disappeared within the last decade due to conversion into agricultural lands with negative consequences on ecosystem services (water and fuel wood) and the microclimate (UNEP/UNDP/GOR 2007).

In terms of climate, the region is a low rainfall zone receiving an annual average rainfall of around 800 mm. Weather data up to date only exists from Kanombe weather station, Kigali (Figure 5). According to UNEP/UNDP/GOR (2007) total annual precipitation shows a declining trend in Bugesera which coincides with reports of increasing droughts during the years 1992, 2000 and in recent years.

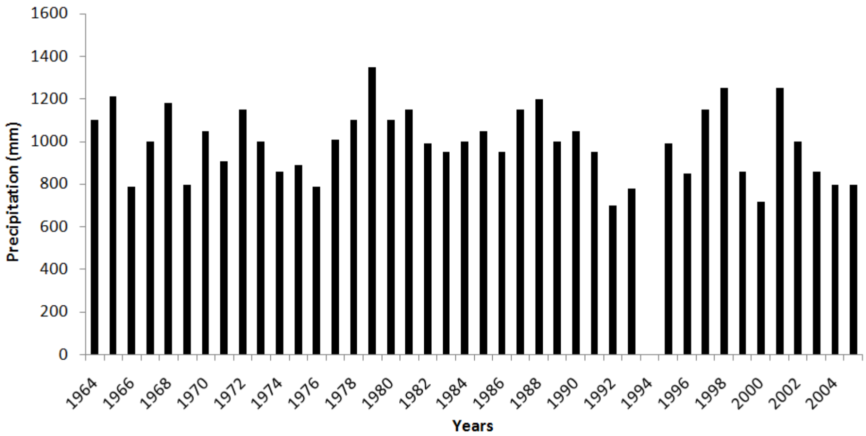


Figure 5. Total Annual precipitation recorded at Kanombe station, Kigali (1964-2005), the nearest weather station from Bugesera.

Water deficits are common in the months from June to August and in October. However, in 2010 ISAR Karama recorded very low rainfall in November and December (55 mm and 29 mm respectively) which explains bush bean crop failures in that season. This crop failure did not allow any biomass, grain yield harvesting, or BNF assessment in Bugesera.

Table 8. Average bio-physical data for the two study sites in Burera and Bugesera

Characteristics		Burera	Bugesera
Altitude (m)[a]		2000	1420
Soil characteristics			
Major Soil types (FAO)[b]		Mollic Andosols	Xanthic/Humic Ferralsols, Haplic Acrisols
pH (H_2O)[c]		6.19	5.91
C (%)[c]		4.65	2.86
N (%)[c]		0.47	0.22
P (ppm)[c]		25.13	45.28
K (cmol kg^{-1})[c]		0.49	0.67
Ca (cmol kg^{-1})[c]		15.48	50.26
Mg (cmol kg^{-1})[c]		3.8	2.47
Na (cmol kg^{-1})[c]		0.09	0.25
CEC (cmol kg^{-1})[c]		24.3	13.15
Clay (%)[c]		20	35
Sand (%)[c]		38	51
Silt (%)[c]		42	14
Weather data[d]			
Mean annual Precipitation (mm)		1100	800
Months of water deficit (mm)		0	June 34, July 69, August 46, October 9
Farming seasons	A	September-January	September-January
	B	February-June	February-June
	C		August-December (in swamps only)
Mean annual temperature (C^o)		18.9	20.6
Max. mean annual temp. per day (C^o)		25	27.1
Min. mean annual temp. per day (C^o)		12.8	14.2
Min. mean annual temp. absolute (C^o)		7.5	8.6

[a]Average of own GPS measurements; [b]Gent University/MINAGRI 2001; [c]Own data (50 soil samples per site); [d] Kinoni weather station (within study area) and Nyamata/Gitagata weather station

3.2 Farming Systems Characterisation of Different Farm Types

In this chapter, the general production system with its different farm components will be described for the two study sites focusing on the agronomic and socio-economic role of common beans. Differences in farm layout and management practises between farms are expressed per farm type. Furthermore, within-farm resource allocation and soil fertility gradients are explored.

3.2.1 Crop Production

Farm Layout

Table 9 shows the average farm and field sizes, no. of fields and distance to fields from the homestead across farm types. Farm size, field size and the number of fields increases with wealth. Farm sizes vary widely within farm types, especially in Bugesera. Each farmer has at least one field near the homestead and, depending on the farm type, more fields further away from the homestead. Accordingly, farmers of Type 1 and 2 have a low mean distance from the homesteads to fields. Farmers' estimates of their farmland correlate significantly with the measured size, which highlights their accuracy in estimations and knowledge on their property.

Table 9. Average farm and field sizes, no. of fields and distance to fields from the homestead per farm type and study site

Farm type	Farm size (ha)	Field size (ha)	No. of fields	Distance to fields (m)[a]
Bugesera				
1	0.42	0.05	5.9	91
2	0.79	0.07	9.5	75
3	0.89	0.13	6.7	465
4	3.26	0.25	15.3	224
Average	1.71	0.15	10.8	207
Burera				
1	0.06	0.03	1.8	72
2	0.34	0.06	4.5	92
3	0.61	0.09	5.3	515
4	1.49	0.15	9.7	401
Average	0.88	0.11	6.7	341

[a] In Bugesera fields in the swamps which are in a distance between 1000-5000 m were excluded.

Figure 6 (A) shows the farm of the widow farmer Rose (farm code 1) in Burera. Her household belongs to farm Type 2 and lives from a total farm size of 0.25 ha with three different crop fields and a few square meters of forest. She keeps two sheep, one pig and one chicken. The fields are all near the homestead (10 m to the fields and 80 m to the forest). The produce is not sufficient to feed of her 3 children. Therefore she has to work for other farmers to be able to buy enough food. Figure 6 (B) shows the farm of Mathias (Type 4) who has many plots and a total farm size of 1.45 ha. Due to his market orientation, he grows potatoes on a realtively large area.

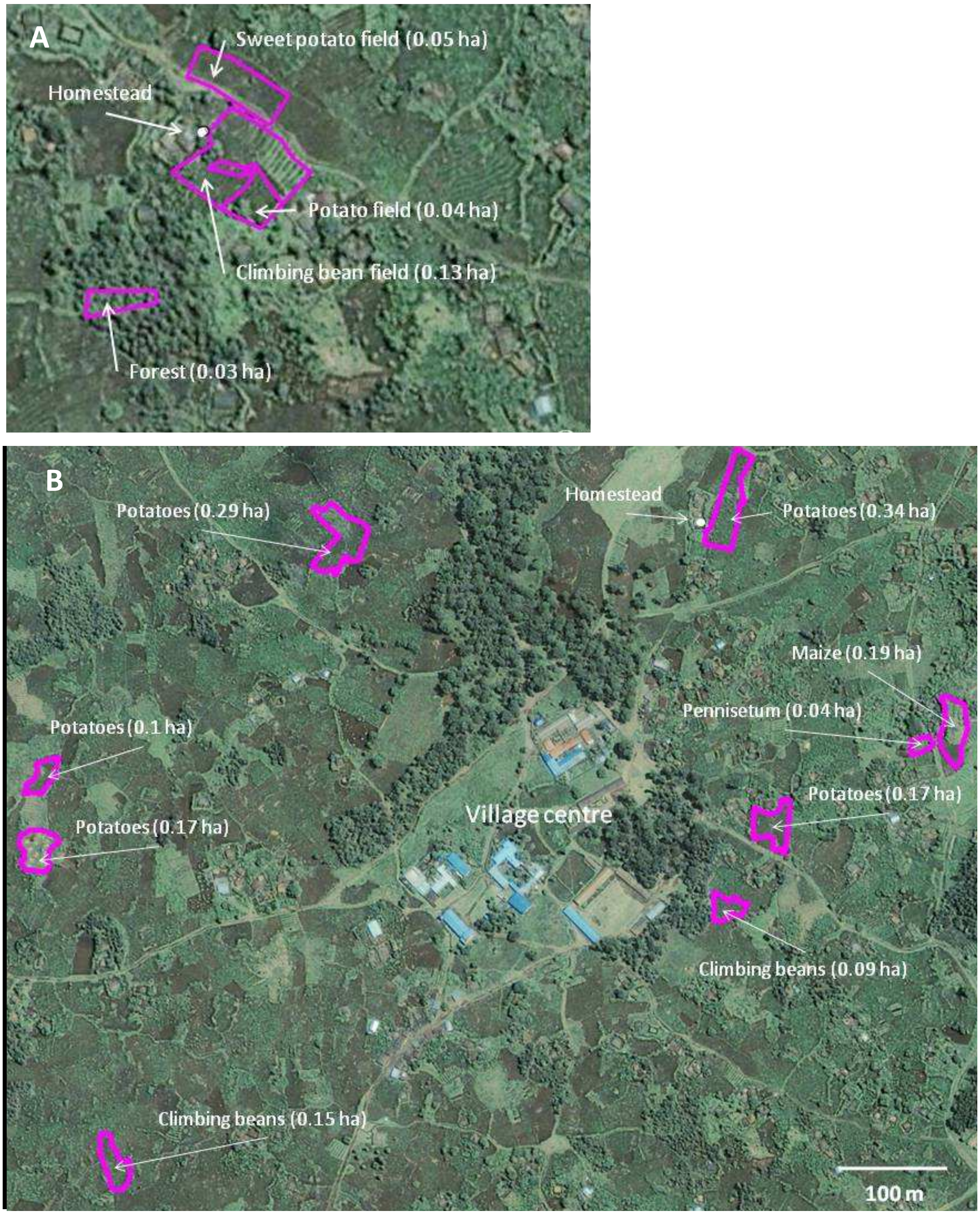


Figure 6. Layout of two studied farms in Burera (A) of farm Type 2 and (B) of farm Type 4

Crop production and Cropping History

In Burera, climbing beans, maize, potatoes, and sweet potatoes are cultivated in season A and B and sorghum only in season B since this season allows a longer growing cycle. In Bugesera, bush beans, maize, groundnuts and potatoes are cultivated in season A and B and sorghum only in season B. In season C, maize and bush beans are cultivated in the government owned swamps. This season overlaps with season A.

To determine changes in land use, the cropping history was assessed for the last 10 years (Table 10). Crops that are cultivated more frequently and whose shares of the total cropland increased are referred to as ‘increasing crops’. Crops that are cultivated less frequently, and on a lowering share of land are ‘decreasing crops’. The share of one crop can increase at one farm and decrease at another. Crops not anymore cultivated by any of the interviewed farmers are ‘abandoned crops’.

Table 10. Farmers' perception on crops with increasing, decreasing importance and abandoned crops

Study site	Increasing crops[a]	Decreasing crops[b]	Abandoned crops[c]
Burera	Climb. beans	Bananas	Garden peas
	Maize	Sw. Potatoes	Wheat
	Potatoes	Potatoes	Finger miller
	Sorghum		Coffee
	Vegetables		Banana
Bugesera	Cassava	Sorghum	Soybean
	Maize	Sw. potatoes	
	Groundnut	Bush beans	
	Beer bananas		
	Coffee		
	Potatoes		

[a] share of the crop increased; [b] share of the crop decreased; [c] crops not cultivated anymore by none of the interviewed farmers.

In Burera, all farmers expanded the cultivation of climbing beans and maize and ranked them as most important. Reasons for climbing bean expansion is the very high food value (and that different plant parts can be consumed), high yields, a relatively short growth cycle, and the high demand on markets. Maize has expanded for the same reasons as beans and additionally, due to the government policy on land consolidation.

All farmers decreased the cultivation of bananas and sweet potatoes and abandoned the cultivation of garden peas, wheat, finger millet and coffee because of a low per area productivity. Besides the low productivity, garden pea is not cultivated anymore due to birds damage and land shortage. It used to be cultivated as a 'fallow crop' to increase soil fertility but farmers do not fallow anymore. Besides, resource-poor farmers (Type 1 and 2) reduced potato cultivation due to low yields when no herbicides and improved seed are used (they do not have the capacity to purchase these). Farmers replaced these crops with beans, sorghum, and maize (Type 1 and 2) and with sorghum, vegetables, and potatoes (Type 3 and 4).

In Bugesera, the cropping history and ranking is more diverse and involves more crops since farming is not yet specialised in that region. The main expanding crop for all farmers is cassava, because of high yields and its tolerance against drought. Maize, groundnut and bush bean cultivation have also been expanded by most farmers because of the government policies of land consolidation in swamps (maize and beans), and high market value and drought tolerance (groundnut). Farmers (especially the resource-poor) reduced bush bean cultivation on hill-fields due to the lack of drought tolerance and replaced the crop with cassava. Farmers rank the importance of bush beans very differently across farms with an average rank of 3 after beer bananas and cassava.

Beer bananas, coffee and potatoes are also expanded by some farmers due to good prices for beer and coffee and because potatoes replaced sweet potato production.

Farmers decreased sorghum cultivation due to severe infestation with *Striga* spp. in recent years. They explain the almost disappearance of sweet potatoes as a result of the government policy on land consolidation which requires maize or bush bean mono-cropping in the swamps, where sweet potato nurseries used to be maintained. Reasons to abandon soybean production were more diverse and included sensitivity to drought, low soil fertility of fields and lack of market access.

The results show that many different drivers exist to rank the importance of crops. Farmers consider bush beans important due to the high value as a staple food crop but due to environmental constraints, farmers do not increase the production on hill-fields. On the other hand, groundnut cultivation is expanded, but farmers did not rank it as very important crop, which suggests that groundnut is considered to have a lower food value relative to beans (groundnuts are not a staple food). Food value might be a stronger driver to rank a crop important than a high agronomic potential and a high market value. This is underlined by farmers low ranking of sorghum in Burera although they increased the cultivation due to a high agronomic potentials and high market value.

Contribution of Crops

Table 11 provides detailed information of the mean crop shares of the total farm over one crop rotation for one year (season 2011A, 2010B and 2010C; compare Annex 6 for the different shares between season A and B).

Table 11. Average percentage of total arable area cropped with different crops for one year (season 2011A, 2010B and 2010C)

	No. of fields	Mean contribution per farm (%)	Mean contribution per farm type (%)			
			1	2	3	4
Bugesera						
Cassava	13	21	37	26	5	12
Banana	17	17	8	20	5	34
Bush beans	19	14	24	10	10	11
Fallow	15	7	4	6	11	8
Coffee	13	4	0	5	5	4
Sorghum	14	6	3	4	7	10
Pennisetum	5	5	0	1	11	7
Potatoes	6	5	1	5	10	2
Groundnuts	9	4	3	5	5	2
Maize	10	4	0	9	7	1
Bush land	2	3	13	0	1	0
Vegetables	5	2	3	1	0	3
Sweet potatoes	3	1	0	3	0	2
Swamp fallow[a]	8	7	3	8	10	8
Burera						
Climbing beans	28	40	50	37	42	26
Sorghum	23	23	21	24	22	26
Maize	20	22	29	20	28	10
Potatoes	9	5	0	5	0	12
Forest	1	4	0	4	0	14
Banana	2	2	0	0	0	9
Sweet potato	2	2	0	9	0	0
Vegetables	3	2	0	1	8	1

[a] Area not possible to be cultivated due to flooding of swamps from December to June

Crops ranked as important and increasing in Bugesera (cassava, bush beans, maize, and beer banana) have the highest share of farm area. Cassava and bush beans mainly occupy large areas of resource poor farms (Type 1), while beer banana is mainly cultivated by farms of Type 4. The share of maize was surprisingly small and was mostly cultivated by farm Type 2 and 3. Bush beans occupy 24% of the land of farmers of Type 1 and 10% of farms of Type 2, 3 and 4. For resource-poor farmers, bush beans are the second most important crop after cassava in spite of drought challenges. Groundnuts occupied only small areas although they were mentioned as ‘increasing crop’. The low share of sweet potato area underlines the effect of the land use change steered by the government. Sorghum is still cultivated on a large area especially by farmers of Type 4, although it was not ranked as very important and even abandoned by some farmers. This could mean that resource-rich farmers still make profit with this crop in spite of Striga infestation, or that they have strategies to deal with the infestation.

In Burera, climbing beans, sorghum and maize occupy the largest areas, with climbing beans having the highest mean share of 40%. Farmers of Type 1, who only have 1-2 fields, cultivate at least one of these per season with climbing beans. With increasing farm area, the share of climbing beans reduces (from 50% to 26%). However, in absolute terms, the share of beans increases in Bugesera from 0.06 ha to 0.61 ha from farm Type 1 to 4. In Burera, the share increases from 0.03 ha to 0.33 ha. However, farmers of Type 4 cultivate a similar area of beans as Type 3, but increase the area of other crops. This indicates a diversification of production of resource-rich farmers. Besides beans, maize and sorghum, they cultivate potatoes, beer banana, pennisetum and own woodlots.

Crop Residue Allocation

The allocation of crop residues (CR), as estimated by farmers, differs by study site, crop and farm type. CR allocation to livestock is higher in Burera than in Bugesera, less CR remain in the field or are allocated for other uses such as for animal bedding or mulching.

In Bugesera, CR of bananas, cassava, potatoes, and sweet potato remain almost completely in the field. One third of bush beans and groundnut and two thirds of maize CR remain in the field, 30% of groundnut and beans are fed to livestock and the remaining third used as mulch for coffee and bedding material for cattle. The remaining third of maize CR are fed to livestock. Coffee CR are burnt to reduce the spread of diseases. In Burera, on average 40% of climbing bean and maize CR are left in the field, 50% fed to livestock and around 10% burnt or used as bedding material for cattle. In contrast to Bugesera, all sweet potato CR and 25% of potato and banana CR are fed to livestock.

In Burera, farmers with increasing wealth allocate less CR to livestock and more to the field to profit from the fertilising effect (Table 12) that all farms are aware of. In Bugesera, the trend is opposite. Wealthier farmers increase the allocation of CR to livestock, keeping less in the field. This can be due to the high numbers of livestock for wealthier farmers and because their other feed sources (Pennisetum, weeds, etc.) are not sufficient. Resource-poor farmers who only have few sources of livestock feed rely on almost all climbing bean and maize CR in order to feed their animals in spite of their knowledge on the positive rotational effects.

Most farmers feed CR to own livestock and only few sell it. If CR are fed to cattle, manure is applied to fields but not necessarily returned to the field of origin. The amounts of manure allocated to fields differ between crops and are highest in potatoes (compare 3.2.2). CR retained on fields remain as mulch layer since they are not incorporated (farmers plough after around two months in the beginning of the next season) and no free roaming animals feed on CR during the dry season.

Table12. Farmers' estimation on crop residue allocation to the field, livestock or to other uses

Farm type	Crop residues allocated (%)		
	Remain in the field	Fed to livestock	Used for others[a]
Bugesera			
1	79	9	12
2	75	0	25
3	32	38	30
4	54	26	20
Burera			
1	10	78	12
2	35	55	10
3	34	54	12
4	59	31	10

[a] mulching banana and coffee, burnt, bedding material (bean shoots) and construction.

3.2.2 Inputs

Labour Allocation

Farmers of farm Type 1 and 2 rely mainly on family labour for all farm activities and farm Type 3 and 4 hire labour for all activities in addition to family labour. Type 4 uses more hired than family labour for individual farm activities except for harvesting bush beans and groundnut in Bugesera (harvested by family members).

Table 13 summarises the labour allocation for different crops across the study sites. Farmers estimated the time spent for different farming activities for small plots, which results in very high values if extrapolated per ha. It remains unclear if this is due to a higher labour input per ha on small plots relative to larger plots or due to overestimations by the farmer. These data can be used to compare the labour input relative to other crops, but total values should be treated with caution. For bush beans, land preparation requires most labour (30% of total labour use), followed by weeding (21%), and post-harvest handling (21%). Planting and harvesting requires 14% and 12% respectively. For climbing beans, land preparation requires also the highest labour (30%), the second highest proportion (14%) is spent on preparing and installing the stakes. Farmers of different farm types did not show clear differences between the labour distribution.

Table 13. Family and hired labour hours per farming activity of selected crops.

Crop	n	Preparatior ($h\ ha^{-1}$)[a]	Seeding ($h\ ha^{-1}$)	Weeding ($h\ ha^{-1}$)	Ridging ($h\ ha^{-1}$)	Harvesting ($h\ ha^{-1}$)	Post-harvest ($h\ ha^{-1}$)	Total ($h\ ha^{-1}$) min	Total ($h\ ha^{-1}$) mean	Total ($h\ ha^{-1}$) max
Bugesera										
Bush beans	12	539	247	376	0	217	384	608	1762	4782
Cassava	4	1033	481	747	158	572	794	2294	3784	5291
Groundnuts	4	1058	226	769	128	792	1130	1437	4104	6826
Maize	6	783	158	354	247	194	639	1447	2376	3566
Potatoes[b]	2	672	154	146	36	253	14	1107	1275	1441
Burera										
Climbing beans[c]	27	846	765	462	0	466	248	724	2786	8472
Maize	7	769	444	514	273	58	22	806	2081	6808
Potatoes[b]	5	1351	455	1581	781	100	0	2324	4268	8119

[a] Sum of family and hired labour days multiplied by the hours worked per day; [b] weeding includes biocide application accounts in Burera for 700 $h\ ha^{-1}$ (only hired labour); [c] Seeding includes 50% of labour for staking.

Farmers invest the highest labour input of >4000 $h\ ha^{-1}$ in groundnuts (Bugesera) and potatoes (Burera). In groundnuts, the harvesting and post-harvest handling requires much higher labour inputs than other crops due to the shelling, drying and sorting. Potatoes are labour intensive due to intensive land preparation, ridging and weekly biocide application in the vegetative stage. In Burera, potatoes are cultivated more intensively (more than two times as much labour for weeding, ridging and biocide application) than in Bugesera, which results in a three times higher productivity of 10 $t\ ha^{-1}$. Vegetable cultivation and (post-) harvesting requires similar amounts of labour as potatoes but only two farmers of Type 4 were growing vegetables. In Burera, farmers spent more labour on seeding and weeding for maize cultivation than in Bugesera where maize is often cultivated in swamps with less agricultural activities. In Bugesera, farmers on the other hand use more labour on harvesting and post-harvest handling since maize is cultivated for marketing and farmers need to shell, dry, and sort it prior to the sales. In Burera, maize is mainly cultivated for home consumption and farmers do not spent much time on post-harvest handling or find it difficult to estimate it.

Inorganic Fertilisers and Biocides

Farmers use synthetic inputs for selected crops and often more than one except those of Type 1 in Bugesera and Type 1 and 2 in Burera.

Mineral fertilisers such as NPK (17-7.5-14.1), DAP (Diammonium phosphate, 18-20.2-0) and urea (46%) are only used for specific crops, and in very low application rates. In Burera, NPK is used for potatoes (maximum of 30 kg ha^{-1}) and DAP for maize and in two fields of climbing beans (maximum of 20 kg ha^{-1}). In Bugesera, NPK is used in coffee and maize and urea for coffee, both with a maximum application of 2.5 kg ha^{-1}.

Insecticides (Cypermethrin 5.44%) and fungicides (Mancozeb 80%) are used by only very few farmers in both study sites. In Burera, insecticides are applied on climbing beans and maize in season B against mealy bugs with maximum amounts of 5.44 ml $season^{-1}$ ha^{-1} active ingredient. Other crops were insecticides are applied are vegetables with maximum amounts of 27 ml $season^{-1}$ ha^{-1} active ingredient. In Bugesera, insecticide use is more common than in Burera due to regular application in coffee with up to 30 ml $season^{-1}$ ha^{-1} active ingredient.

Farmers apply fungicides in potatoes against *Phytophthora infestans* on all fields of farm Type 3 and 4 (not on those of Type 2 and farmers of Type 1 do not grow potatoes). The maximum applied amounts are 264 g $season^{-1}$ ha^{-1} active ingredient. Fungicides are not applied in Bugesera except in tomato cultivation (maximum of 250 g $season^{-1}$ ha^{-1} active ingredient).

Governmental and NGO programmes influence the availability of inorganic fertilisers and biocides by donating or subsidising these. Within the policy on land consolidation, inputs are subsidised by 50% for maize and bush beans in Bugesera and maize in Burera. Insecticides for coffee, are available at no costs through the local government in Bugesera. However, all inputs are also available in farm shops at regular prices.

Organic Fertiliser

The main fertiliser used in both study sites is composted animal manure. Table 14 summarises the application rate and nutrient contents of animal manure and mineral fertiliser for different crops. It highlights the relative importance of animal manure compared with mineral fertiliser. However, if farmers apply mineral fertilisers (e.g. in maize in Burera), the nutrient input is relatively important especially for P inputs.

Farmers estimated the amounts of animal manure applied for small plots (except for bananas), which results in relatively high values if extrapolated to a per ha basis. It is likely that farmers overestimated the manure application rates given the very large application rates especially in bananas relative to the number of livestock and farm size farmers own. These data can be used to compare the manure application rates relative to other crops, but total values should be treated with caution. Measuring the actual amounts of manure applied and tracing the source of manure could be useful to understand better crop-livestock interactions.

All farmers of all farm types use organic manure except for two farms without livestock in Bugesera (from farm Type 1 and 2). The main source of manure is the livestock kept at the homestead (own property or on loan), especially cattle. In Bugesera, more manure is applied to crops due to a higher animal density per farm. In Burera, 90% of the fields are fertilised with rates between 0.5 and 29.9 t ha^{-1}, whereas in Bugesera only 39% of fields receive organic manure between 2.4-120 t ha^{-1}. Highest amounts are applied to bananas in Bugesera with 20 to 120 t ha $season^{-1}$ from farm Type 1 to 4. Resource-rich farmers applying highest amounts of manure buy manure from other farmers or receive manure in exchange for Pennisetum.

Table 14. Fertiliser application rates per farm and nutrient contents of manure and mineral fertilisers

Crop	n[a]	Type of fertiliser	Application rate (kg ha^{-1})[b]	Nutrient contents (kg ha^{-1})[c]		
				N	P	K
Bugesera						
Banana	15	Animal manure	52 730	100.2	42.2	158.2
Bush beans	17	Animal manure	6 200	11.8	5.0	18.6
Maize	10	Animal manure	3 650	6.9	2.9	11.0
	3	Mineral	2.5	0.4	0.2	0.4
Burera						
Climbing beans	23	Animal manure	5 680	10.8	4.5	17.0
	2	Mineral	20	3.6	4.0	0
Maize	19	Animal manure	2 280	4.3	1.8	6.8
	7	Mineral	20	3.6	4.0	0
Potatoes	9	Animal manure	10 850	20.6	8.7	32.6
	8	Mineral	30	5.1	2.2	4.2

[a] Number of fields where fertiliser is applied; [b] Average application of composted animal manure (fresh weight) and maximum application of mineral fertiliser; [c] Animal manure: fresh weight of composted cattle manure in East Africa contains around 0.19% N, 0.08% P and 0.30% K based on estimates by Bekunda and Manzi (2003).

3.2.3 Bean Cultivation Characteristics

Varieties and Seed System

Common beans were introduced to Rwanda from Latin America. While bush beans were cultivated by most farmers in the country in the 1980s, climbing beans were only cultivated by few farmers in the North-West in small isolated pockets at that time. To increase the cultivated area of climbing beans, research has concentrated on improved varieties and staking technologies since the 1970s. Since then, the area under climbing beans has increased. A survey conducted in 1992/1993 reports that over 40% of Rwandan bean farmers grew improved climbing beans especially in the North (Sperling and Muyaneza 1995).

Improved bush and climbing beans, originate from centralised bean breeding programs, initiated, and implemented by national and international research centres (ISAR and CIAT).

In Bugesera, farmers cultivate determinate bush bean varieties of Type I (Laing et al. 1984) which mature in around 90 days. Very few farmers experiment with indeterminate or intermediate climbing varieties. Farmers often cultivate variety mixtures and could not further specify the varieties which they purchase from local markets and from neighbour farmers (farmers strategies to deal with seed diversity are reported by Sperling, 2001). For the cultivation of beans in the consolidated swamps, farmer associations are supposed to offer improved seeds (which were not available in 2010).

In Burera, indeterminate climbing bean varieties of Type IV (Laing et al. 1984) are grown. Farmers knew the varieties and were able to compare their performance.

Besides resource-poor farmers (Type 1), who cultivate variety mixtures, the improved varieties are cultivated by farmers. Varieties differ in yield potentials, taste, colour, and pest/disease characteristics (Annex 5 summarises the farmers' perception on the varieties characteristics and by whom they were distributed).

The climbing bean variety Nyiragateya differs much from the others because it is especially suitable to be consumed as fresh green bean. Resource-poor households prefer this variety because they cannot wait for the seed to mature due to food shortage. Serayi and RWV 2070 are varieties said to be high yielding and tasty but having pest problems. In fields with Serayi beans, farmers mention that mice damage causes crop failure. In 2010, N_2Africa introduced the new varieties RWV 2070 and Gasirida. Farmers report that both are high yielding in terms of dry grain yield but green beans are not suitable for consumption. RWV 2070 is susceptible to bird damage.

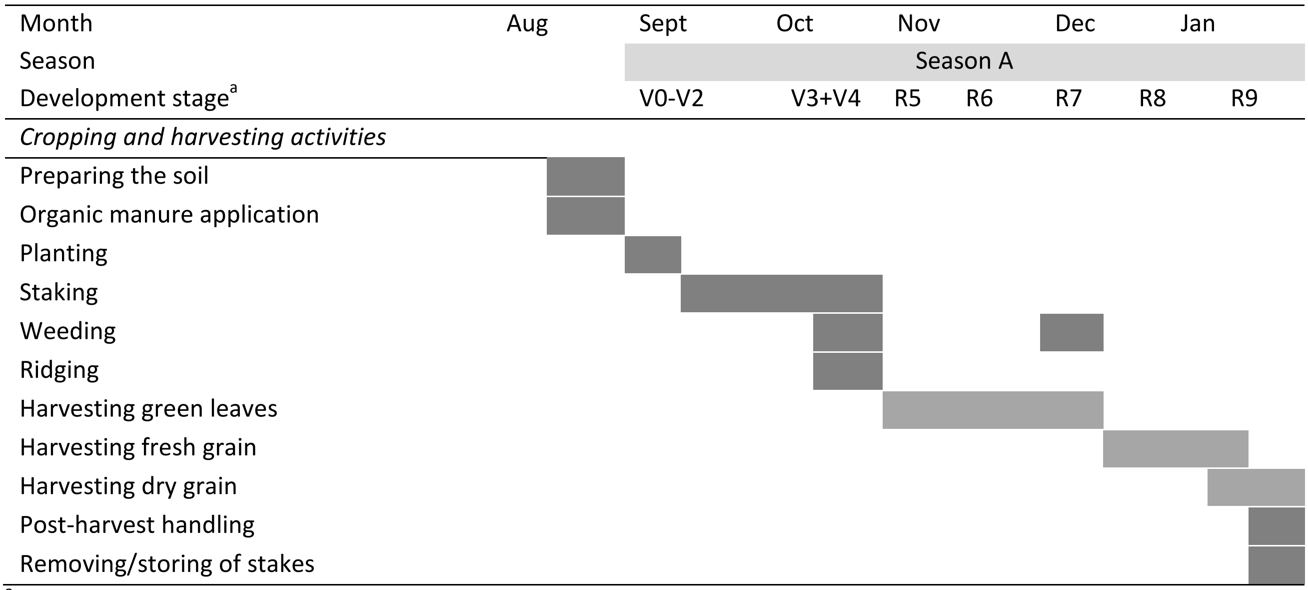
With increasing wealth, farmers keep more seed for the next season to have control over the seed quality. In Burera, farmers of Type 1 do not keep any seed because they consume the whole produce due to food insecurity. Therefore, they purchase seed from local markets, which are variety mixes that farmers consider less productive.

Cultivation Practises

Bush beans are sown by broadcasting and sometimes intercropped with maize. Planting in season 2011A started in the end of October after the land had been prepared. First weeding was completed in December. In the season studied, no further activities were carried out due to severe drought in December and January that led to crop failure and no harvest of beans (reported by CIAT Rwanda). In other years, farmers harvest beans in early January.

Climbing beans are cultivated in lines or by broadcasting with different amounts of seed per planting hole. Spacing therefore ranges from 12 to 32 plants m^{-2} with a mean spacing of 21 plants m^{-2}. Planting dates differed between the first and last week of September. In season A, the activities in climbing bean cultivation include land preparation, manure application and planting in September, preparation and installation of stakes, weeding and ridging in October (Figure 7). Farmers weed a second time in December.

Harvesting starts in November (stage R5 to R7) when households pick and cook fresh leaves as vegetable and continue in December and January to harvest green beans (with half-filled pods, R8). For resource-poor farmers, fresh bean products are of great importance for food from November to January since prices are highest towards the end of the growing season when stored stocks finish. The last 2-3 weeks of January, pods containing dry grain are harvested (R9) and stored for own consumption, seed, and marketing or sold directly.



[a] CIAT classification: Fernandez et al. 1986, cited in Van Schoonhoven and Pastor-Corrales 1987

Figure 7. Cropping and harvesting activities in climbing beans in Burera for season A.

Organic Manure

Farmers apply higher amounts of organic manure to bush and climbing beans (Table 16) compared to maize in both study sites, which is in line with the farmers ranking of the crop importance (compare 3.2). In climbing beans, resource-rich farmers tend to use higher application rates than resource-poor farmers.

Climbing Bean Stakes

In Burera, stakes for climbing bean cultivation are an essential, scarce, and very costly resource that requires high labour input. Main staking materials are wood species (60%) such as *Alnus acuminata*, *A. nepoleusis* Schlectendal and *Grevilea robusta* Cunn or *Pennisetum purpureum* Schum. (38%) and *Ricinus communis* L. is used rarely (2%), especially by very resource-poor farmers.

The origin of materials varies. For Pennisetum, a regular practise is that farmers grow it as feed for their livestock and stake production. Especially on remote fields of wealthier farmers, Pennisetum is cultivated on field borders. The quality is relatively high due to a straight shape but depends much on the height and strength (age and diameter). Wooden stakes are of better quality in terms of strength but often not as straight and long. They originate from trees on field borders, wood lots and communal land (e.g. from roadsides). Ricinus grows wild or is cultivated in fields and on field borders. Ricinus stakes are of lower quality since they are generally shorter and lack stability.

Farmers use different staking materials in varying shares depending on the availability of materials on their farm and on the market. All farmers purchase a share of the stakes (on average 20%).

From the purchased stakes, farmers of Type 1 and 2 purchase around 90% wood species and farmers of Type 3 and 4 around 80% Pennisetum. The price varies according to the material. Wood species are cheaper per stake and season because they can be used for 4 seasons compared to Pennisetum which only last for 1-2 seasons.

The proportion of expenses on stakes of the total climbing bean production costs are relatively high with 27% on average (considering family labour as opportunity cost). For resource poor farmers (Type 1) the share is much higher with an average of 39% whereas farmers of Type 4 only spend 19% on stakes. If family labour is not considered as cost, stakes are the main expense for resource poor farmers (Type 1 and 2).

Farmers practise single staking with on average 10 plants per stake and a mean staking density of 22.000 stakes ha^{-1} (16.000-32.000 stakes ha^{-1}). The average height of stakes in farmers' fields in Burera is 190 cm (110-280 cm) but varies a lot between and within fields.

Wealthier farmers (Type 3 and 4) use higher stake densities per ha than resource poor farmers (Type 1 and 2) as indicated in Table 15. Wealthier farmers also tend to have higher stakes but do not rely on specific materials.

Table 15. Average number of stakes per ha, height and percentage of material used for staking

Farm type	No. of stakes/ha	Height (m)	Pennisetum (%)	Wood (%)
1	18 000	178	31	60
2	19 000	168	28	72
3	24 000	206	48	52
4	22 000	200	34	51

The effect of stake density and height on climbing bean grain yield is elaborated in chapter 3.3.

Yields

Yields estimated by farmers (based on experiences of previous years) ranged from 0.12 to 2.11 t ha^{-1} with an average of 0.91 t ha^{-1} (Table 16). Similar yields are obtained of groundnuts with shell (1.02 t ha^{-1}), the second grain legume cultivated in the studied farms in Bugesera.

Table 16. Estimated grain yields of bush beans and groundnut in Bugesera, in 2011A

Farm type	Dry grain yield (t ha^{-1})	
	Bush beans	Groundnut (with shell)
1	0.90	-
2	0.82	0.41
3	1.01	0.76
4	0.93	1.55
Average	0.91	1.02

Yields of climbing beans need to consider the different harvested products: fresh leaves, fresh (green) pods, fresh grain and dry grain. The amount of fresh leaves and fresh pods was not quantified since these are picked continuously by different household members and cooked immediately.

Measured fresh and dry grain yield and above ground biomass yield is summarised per farm type in Table 17. Farmers of Type 1 harvest highest amounts of fresh grain, around 0.2 t ha season^{-1} in DM (including pods).

Table 17. Measured fresh and dry grain yields and above ground dry biomass for climbing beans

Farm type	Grain yield (t ha^{-1})			Above ground dry matter yield (t ha^{-1})
	Fresh grain[a]	Dry grain	Total (fresh+dry grain)	
1	0.24	1.18	1.42	5.47
2	0.04	1.14	1.18	4.89
3	0.05	2.02	2.07	5.25
4	0.08	2.27	2.35	4.24
Average	0.08	1.88	1.96	4.89

[a] Assuming that fresh grain including pods has a 30% dry matter content

Mean dry grain yields are 1.88 t ha^{-1}, ranging from 0.63 to 3.78 t ha^{-1} (excluding pods). Resource poor farmers (Type 1) have a lower productivity than farmers of Type 4 with mean grain yields of 1.18 and 2.27 t ha^{-1}, respectively. If fresh grain is also considered, yields of farmers of Type 1 increase. Farmers' yield estimates for climbing beans were very close to the measured data and farmers more often underestimated than overestimated the yields. Above ground dry matter yield is little variable across farm types and is not correlated with dry grain yield.

3.2.4 Animal Husbandry

Farmers in Bugesera keep more animals per farm compared to Burera. The number of small livestock and cows increase with wealth (Table 18). Four resource-poor farmers keep cows of wealthier farmers on loan.

Table 18. Average number of cows, goats, chicken, pigs, and sheep per farm and farm type

Farm type	Number of animals per farm (no.)				
	Cows	Goats	Chicken	Pigs	Sheep
Bugesera					
1	1.0	2.0	1.0	0.0	0.0
2	2.0	5.0	6.5	0.0	0.0
3	3.0	4.3	9.7	0.0	0.0
4	2.7	4.5	3.0	2.0	0.0
Burera					
1	1.0	0.0	0.0	0.0	1.0
2	1.0	1.0	1.0	1.0	1.5
3	1.7	2.0	0.0	1.5	2.5
4	2.0	2.5	8.5	1.0	2.5

The inputs needed for animal husbandry are mainly labour and feed (land is needed to produce feed but not for free grazing). Labour and feed are very scarce resources especially for poorest famers of farm Type 1 who sell their labour to other farmers and have weeds from fields and communal land such as roadside as often only available feed.

Most common feed types are Pennisetum, bean and maize CR and weeds collected from fields and communal land and for pigs grains of maize and the residues of sorghum beer making. Separate Pennisetum fields are only common among farmers of Type 3 and 4, others harvest it from field borders or through the exchange against manure with wealthier farmers. Purchasing feed is not common, only few farmers of Type 3 and 4 buy supplementary Pennisetum. None of the farmers however mentioned to sell any feed.

Farmers collect and composted manure from cows and partly from the other livestock. In Burera, farmers have compost pits often protected by a shading made of local materials. In Bugesera, farmers keep manure on heaps near the stables and not protected against the sun and rain.

There is high variability of the milk productivity of cows, ranging from 2 to 14 kg day^{-1} in Bugesera and 1 to 5 kg day^{-1} in Burera. In both sites the productivity of cows from poor farmers is lower compared to the wealthier farmers. In Bugesera, cows have higher productivity compared to Burera due to better available feed resources. Besides, in Burera many farmers keep cows only recently and have therefore younger cows and farmers are less experienced in managing them adequately.

3.2.5 Soil Fertility

Table 19 shows the variability of soil parameters across farm type and study site (swamp fields are shown separate).

In Bugesera, farm type has little effect on the average soil fertility of fields. However, the fields in the swamps of peat soils, have much higher concentrations of organic C, total N, and exchangeable Ca, Mg, Na, and CEC and are more often farmed by resource-rich farmers. Fields of Type 3 and 4 farms have higher average P concentrations probably due to higher manure application and fields of Type 4 farms have on average higher organic C concentrations.

In Burera, fields of poor resource endowment farms (Type 1) have statistical significantly lower concentrations of organic C and total N and lower Ca which might be the result of a landscape effect (compare 3.3.2).

Table 19. Average soil parameters per farm type and study site

Farm type	n	pH	C %	N %	P ppm	CEC cmol kg^{-1}	K cmol kg^{-1}	Ca cmol kg^{-1}	Mg cmol kg^{-1}	Na cmol kg^{-1}	Clay %	Sand %	Silt %
Bugesera													
1	8	5.6	2.1	0.2	22.2	12.3	0.60	5.6	1.8	0.08	30.4	54.9	14.7
2	15	6.1	1.5	0.1	18.6	10.5	0.67	5.8	1.9	0.10	35.2	51.0	13.8
3	9	6.1	1.8	0.1	92.1	12.5	0.90	6.7	2.2	0.13	35.4	49.3	15.3
4	13	5.8	5.0	0.1	32.5	22.3	0.74	9.3	3.0	0.58	32.9	49.8	17.3
Swamp fields													
3, 4	2	5.1	24.4	1.74	7.3	54.5	0.37	24.2	11.5	3.44	22.5	58.9	18.6
Burera													
1	5	6.3	3.2	0.32	20.9	17.8	0.78	10.6	3.4	0.10	16.1	39.5	44.4
2	11	6.1	5.9	0.60	9.8	25.3	0.54	16.0	3.7	0.10	16.5	40.8	42.7
3	15	6.1	4.5	0.46	22.6	24.2	0.50	14.8	3.8	0.11	20.8	37.6	41.6
4	21	6.3	4.3	0.44	37.8	25.7	0.40	17.0	4.0	0.07	21.4	36.4	42.2

The farmers' perception of soil fertility was correlated to soil fertility parameters, management indicators and biomass and grain yield, resulting in no significant correlations.

Farmers allocate crops to fields according to their perceived fertility. In Bugesera, farmers grow bananas on fields ranked as most fertile and cassava on rather unfertile fields. Bush beans are grown on all types of fields. In Burera, climbing beans, maize and potatoes are cultivated on the very fertile and fertile fields. Farmers also grow climbing beans on perceived unfertile and very unfertile fields. Fields with severe slopes are always cropped with climbing beans and sometimes maize, whereas potatoes are typically grown on fields in the lowlands.

The influence of soil fertility on the allocation of crops, is summarised in Table 23. In Burera, farmers grow potatoes on fields statistically significantly higher in C and N contents than beans and maize. Available P and clay contents are statistically significant higher in fields of maize compared to climbing bean fields. In Bugesera, clay content is significantly higher in cassava fields compared to bean and maize fields.

In Burera, fields with climbing beans have lower concentrations of total N (0.45% N) compared to non-bean fields (0.56% N) and lower concentrations of available P (15 ppm) compared to the non-bean fields (24 ppm). This might be the case because beans are cultivated on relatively good and poor fields in terms of fertility and slope and because more manure is applied to non-bean fields e.g. potatoes. In contrast, maize and potatoes are only cultivated on fields in the valleys.

In Bugesera, bean fields have no effect on total N but available P is higher in bean fields with 45.7 ppm compared to the non-bean fields with 34 ppm.

Table 23. Measured soil fertility parameters averaged per crop

Crop	n	pH	C %	N %	P ppm	CEC cmol kg^{-1}	K cmol kg^{-1}	Ca cmol kg^{-1}	Mg cmol kg^{-1}	Na cmol kg^{-1}	Clay %	Sand %	Silt %
Bugesera													
Bush beans	16	6.0	2.6	0.14	45.7	14.4	0.74	6.9	2.3	0.22	33.8	50.9	15.3
Cassava	8	5.6	2.1	0.17	41.1	12.2	0.62	6.0	2.1	0.06	38.9	50.1	11.1
Groundnuts	7	5.9	1.6	0.12	26.7	11.1	0.66	5.6	1.9	0.10	31.6	52.9	15.6
Maize[a]	5	5.8	7.8	0.12	22.2	10.4	0.52	10.3	4.7	1.01	31.3	56.1	12.6
Potatoes	3	5.7	2.4	0.19	94.5	14.5	0.62	7.6	2.0	0.10	31.8	48.9	19.3
Sweet potatoes	2	5.8	1.7	0.13	13.8	10.9	0.38	6.0	1.7	0.11	40.9	42.9	16.3
Vegetables	2	6.3	2.6	0.20	35.1	16.9	0.72	9.6	3.6	0.13	34.9	51.8	13.4
Banana	1	6.2	1.4	0.11	9.2	10.9	0.71	6.5	1.6	0.15	33.6	57.2	9.3
Burera													
Climb. beans	25	6.1	4.5	0.45	14.7	24.3	0.44	15.4	3.6	0.09	19.1	38.2	42.7
Maize	18	6.3	4.0	0.41	27.1	22.6	0.51	14.2	4.0	0.09	22.0	36.1	41.8
Potatoes	7	6.1	6.3	0.65	48.7	27.0	0.48	17.7	3.5	0.08	17.6	40.7	41.6
Sweet potato	1	6.1	5.9	0.62	9.9	30.4	0.68	20.1	3.9	0.10	18.1	36.3	45.6
Vegetables	1	6.1	5.8	0.58	4.6	25.1	1.04	15.2	3.8	0.10	14.5	45.9	39.6

[a] Two fields are located in the swamps

3.2.6 Socio-economics

Food Production

To assess the capacity of the studied farming systems to produce food, gross food production (GFP) was calculated per farm (Table 24). Whereas farmers in Bugesera produce on average 1316 kg of produce from edible crops in dry matter (DM) per farm, farmers in Burera produce only 956 kg DM per farm. However, not all food produced is consumed by the household, but surpluses are sold on the market, processed or kept as seed. Gross food consumption (GFC) is calculated as the food produced and consumed per farm. The GFC is very similar in both sites, implying that in Bugesera much of the produce is sold and processed. The GFP and GFC per household member highlight the available produce per person living and eating in the household. Although the GFC gives an indication on the food consumed from own sources, it does not take into account the produce bought from outside. Therefore, the GFP could be considered a better indicator for food self-sufficiency if assumed that part of the proportion sold at the harvest is bought back from outside during the year.

The calorie and protein content of all edible crops are multiplied with the DM yields per season and divided by the no. of household members and days, as an indicator for the food self-sufficiency. For farmers of Type 1, the food production in terms of calories and protein, is below the recommended level estimated for Rwanda of 2 100 Kcal person^{-1} day^{-1} and 59 g protein person^{-1} day^{-1} (WFP 2005). For farmers of Type 2, the caloric and protein production is comparable to the recommendation in Bugesera and below that in Burera. In farms of 3 and 4, the caloric and protein production exceeds the recommendation.

Table 24. Total and per household member (HHm) gross food production (GFP), gross food consumption (GFC), gross food yield (GFY), energetic and protein production in dry matter per farm

Farm type	total GFP (kg $farm^{-1}$)[a]	total GFC (kg $farm^{-1}$)[b]	total GFY (GFP kg ha^{-1})[e]	GFP (kg HHm^{-1})[c]	GFC (kg HHm^{-1})[d]	Energy (kcal HHm^{-1} day^{-1})	Protein (g HHm^{-1} day^{-1})
Bugesera							
1	164	106	694	38	26	708	16
2	641	372	927	120	70	2476	57
3	942	340	1 084	173	62	3475	119
4	3 518	1 081	1 051	453	138	8345	197
Average	1 316	475	939	196	74	3751	97
Burera							
1	50	50	1 096	15	15	280	16
2	409	212	1 141	55	29	1018	41
3	1 069	473	1 782	198	88	5803	231
4	2 295	915	1 698	328	131	6649	237
Average	956	412	1 429	149	66	3438	131

[a] Gross food production (GFP) in dry matter (DM) per season 2011A of all fields, including all edible crops, irrespective of the type (tubers, grains etc.); DM percentages were obtained from literature
[b] Gross food consumption (GFC) is the GFP consumed, excluding the amounts sold and kept as seed
[c] GFP/HHm is the GFP divided by the no. of household members (family and permanent labourers)
[d] GFC/HHm is the GFC divided by the no. of household members (family and permanent labourers)
[e] Gross Food Yield (GFY) is the GFP of the total farm divided by the total farm area (farm scale GFY)

Although GFP and GFC are generally higher in Bugesera per farm due to larger farms, the edible DM yield ha^{-1} (gross food yield, GFY) indicates a higher productivity of food crops in Burera per unit area (kg ha^{-1}) which might be a result of intensified production or fields that are more fertile.

Within the study sites, food produced (GFP and GFC) increases clearly with farm type, which is partly due to the larger farm size of wealthier farms. In Burera, the trend is extreme, where farmers of Type 1 and 4 produce 15 kg and 328 kg of edible produce (GFP) per household member. This highlights the food insecure status of resource poor farmers of Type 1 and 2, which is more severe in Burera compared to Bugesera.

Nevertheless, resource poor farmers in Burera have a similar high productivity (GFY) per unit area of >1000 kg ha^{-1}. Contrastingly, the productivity of wealthier farmers in Bugesera is much higher compared to the resource poor. This indicates high input intensive farming practises of wealthier farmers in Bugesera and highlights that resource poor farmers in Burera achieve high outputs in spite of their resource constraints, which might hint at high inherent soil fertility.

Food security differences across farm types become obvious when farmers' management of produce is considered. In both sites, farmers of Type 1 consume most of the harvest of food crops (100% in Burera), and hardly sell or keep seed for next seasons (Table 25). With increasing wealth, farmers reduce the proportions consumed and increase the amounts sold and kept as seed. In terms of animal products, households in Burera and Bugesera consume 92% and 68% of the milk, respectively and sell most of the other animal products (meat, eggs etc.).

Table 25. Harvested products consumed, sold and kept as seed by farm type and study site

Farm type	Proportion of harvested produce (%)		
	consumed[a]	sold[b]	kept for seed[c]
Bugesera			
1	75	22	3
2	44	47	9
3	40	49	11
4	31	56	12
Burera			
1	100	0	0
2	70	23	7
3	36	53	11
4	36	43	21

[a] In Bugesera, cassava, bush beans, maize, cooking banana, vegetables, potatoes, groundnut, sweet potato; In Burera, climbing beans, maize, potatoes, sweet potato, vegetable, cooking banana

[b] In Bugesera, cassava, bush beans, maize, beer banana, vegetables, potatoes, groundnut, coffee; In Burera, climbing beans, maize, potatoes, vegetable, beer banana

[c] In Bugesera, bush beans, maize, potatoes, groundnut; In Burera, climbing beans, maize, potatoes

As shown in Table 26, maize, cassava and groundnut have the highest energetic yield and maize, groundnut and beans the highest protein yield in Bugesera. Due to very high maize yields in Bugesera, maize has a higher energetic and protein yield per ha than bush beans. Cassava, the main staple food crop in Bugesera, shows very high energetic and low protein values. In Burera, potatoes have the highest energetic yield and higher protein yields relative to maize. Climbing beans have the highest protein yield and a comparable energetic yield with maize.

Table 26. Dry matter yield, energy and protein production per ha for selected crops (1 kcal = 0.004 MJ)

Crops	n	DM yield (kg ha^{-1})	Energy (MJ ha^{-1})	Protein (kg ha^{-1})
Bugesera				
Bush beans	19	771	10 748	193
Cassava	12	1 526	29 842	46
Groundnut	9	808	19 274	210
Maize	10	2 720	38 953	245
Potatoes	6	321	5 369	32
Burera				
Climbing beans	27	1 717	23 937	429
Maize	20	1 601	22 929	144
Potatoes	8	2 378	39 822	238

Source: Annex 4

Markets and Marketing Strategies

In Bugesera, the market is difficult to access for all farmers (Figure 8). The nearest market is the district capital Nyamata that is located at a distance of 12-18 km (depending on the farm location) accessible via on a non-tarred road with no public and little private transport. To access this road, farmers have to transport their produce on narrow and often steep paths.

Due to high transportation costs, farmers often sell their produce to intermediaries at lower prices. Only farmers of Type 3 and 4 own bicycles to transport the farm produce and thus avoid transportation costs. Resource poor farmers therefore depend more on intermediaries than wealthier farmers do.

Maize and beans cultivated in the swamps administered by associations must only be sold to these and not be used for home consumption (including fresh and dry crop products).

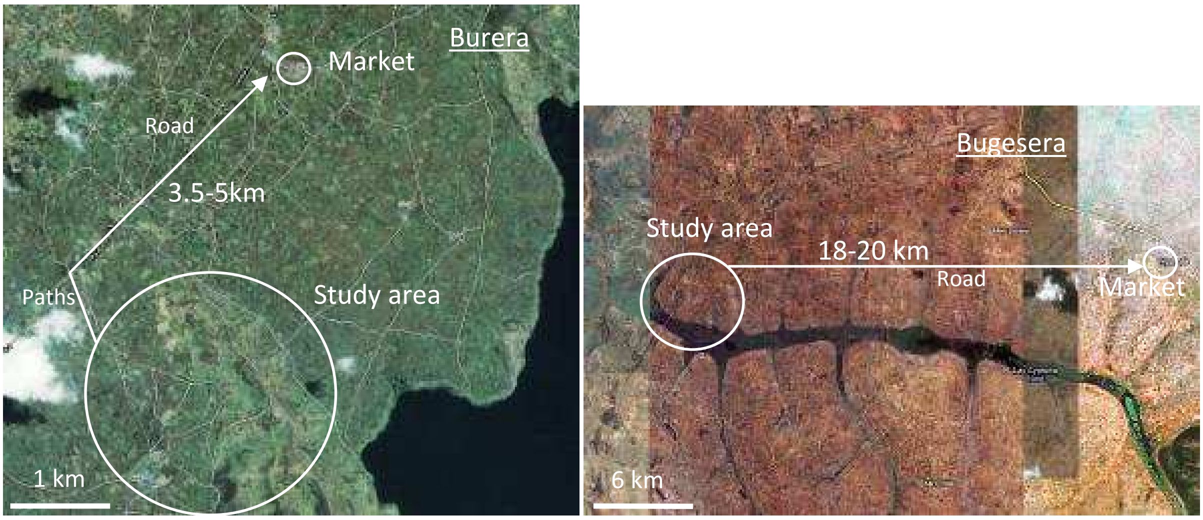


Figure 8. GoogleEarth satellite images of the study areas and distances to markets (accessed 20/02/2011)

In Burera, farmers have higher market access compared to Bugesera. The trading centre with a local market (where all farm produce can be sold) is in a distance of 3 km on a tarred road (0.5-2 km from the homesteads) where public and private transport passes frequently. Transportation costs are therefore lower.

In case of bulky produce (potatoes) and large quantities, farmers of farm Type 4 in Burera often sell to intermediaries. These harvest the crop themselves and pay directly in cash on the farm. This strategy reduces labour input and transaction costs and minimises risks of fluctuating prices on the market for the farmers.

To increase prices, farmers can avoid intermediaries, organise own transportation or store produce until prices increase.

Crop Production Costs, Crop Value and Net Benefits

As shown in Table 27, crop production costs, crop value and net benefits vary much between crops and study sites. Production costs include farmers estimates for different farming activities which can be used to compare labour costs relative to other crops, but total values should be treated with caution (3.3.2).

In Bugesera, groundnuts, maize and cassava have positive net benefits. Net benefits of groundnuts are highest due to a high crop value (high prices of grain). Maize cultivation has high crop values due to high yields because of the cultivation in the fertile swamps. Bush beans and potatoes have negative net benefits. In potatoes, costs of planting material exceed the crop value and in bush beans, labour costs are similar to other crops but crop value is much value due to low prices and yields.

In Burera, potatoes have the highest net benefits due a very high crop value. Climbing beans cultivation lead to positive net benefits due to the high crop value in spite of higher production costs due to stakes. Maize leads to low net benefits due to a low crop value because of low market prices and low yields.

In general, expenses on labour account for the highest share of crop production costs (except potatoes) ranging from 22% to 100% if opportunity costs of family labour are considered with same labour prices as hired labour. Production costs increase with farm type for all crops, especially because wealthier farmers invest more into labour.

Table 27. Crop production costs, crop value and net benefits from selected crops (870 RWF = 1 EUR)

Crop species	n	Crop production costs (1000 RWF ha^{-1}) Hired & family labour	Other inputs	Planting material	Crop value (1000 RWF ha^{-1})	Net benefit (1000 RWF ha^{-1})
Bugesera						
Groundnuts	4	349	0	90	1.010	571
Maize	6	202	1[a]	2	448	243
Cassava	5	161	0	0	267	106
Bush beans	12	255	0	8	249	-14
Potatoes	2	108	0	300	289	-119
Burera						
Potatoes	5	363	8[c]	300	1.783	1.112
Climbing beans	27	256	105[b]	8	555	186
Maize	7	247	1[a]	2	281	31

[a] synthetic fertiliser, [b] stakes, [c] biocides

In Burera, wealthier farmers growing climbing beans spend noticeably larger proportions of the production costs on labour (and synthetic inputs) and a smaller proportion on stakes and seed than the resource-poor farmers. Especially for the latter, around half of the production costs are spent on staking materials (Table 28). If the production costs are considered without the opportunity costs for family labour, stakes account for 75% and 58% of the costs for Type 1 and 2, respectively, and the remaining 25% and 42% for seed.

Crop values of climbing beans are 555,000 RWF ha^{-1} which is twice as high as of maize (in Burera) and bush beans. The high crop value results in high positive net benefits for climbing beans compared to average bush bean benefits, which are slightly negative. Potato crop values are double has high as of climbing beans and net benefits are six times as high.

Climbing bean is the crop contributing highest to the income except for farms of Type 4 who grow potatoes. For all farm types, income from climbing beans is higher than from maize. Compared to other crops, bush beans in Bugesera are much less important for income generation.

Table 28. Major crop production costs for climbing and bush beans per farm type (870 RWF = 1 EUR)

Farm type	n	Crop production costs (1000 RWF ha^{-1}) Family labour	Hired labour	Fertilizer and biocides	Seed	Stakes	Total expenses
Bush beans							
1	4	281	0	0	8	-	289
2	5	145	0	0	8	-	153
3	6	34	77	0	8	-	119
4	4	58	374	0	8	-	440
Climbing beans							
1	3	131	0	0	8	103	242
2	3	188	0	117	8	84	281
3	10	121	107	38	8	130	365
4	12	0	329	729	8	91	428

In Bugesera, farmers growing bush beans spend the largest proportion of costs on labour. Production costs do not clearly increase with wealth as in Burera. Type 1 and 4 have the highest labour costs, which might suggest that small fields require more labour, and that market-oriented farmers use more labour for production. Fields of medium size (Type 2 and 3) require less labour. If opportunity costs for family labour are excluded, the supposedly low costs for seed account for almost 100% of the production costs.

Across farm types, crop value of climbing beans increases with increasing wealth in Burera (Table 29). In Bugesera, the crop value of bush beans does not change across farm types. Net benefits increase from Type 1 to Type 3 in both sites.

In both sites, farms of Type 4 have lower net benefits compared to farms of Type 3 with even negative values in Bugesera. There farmers have very high expenses especially for hired labourers. In comparison with groundnuts, net benefits increase very strongly with increasing wealth.

Table 29. Total expenses, crop value and net benefits across farm types for bush and climbing beans (870 RWF = 1 EUR)

Farm type	n	Total expanses (1000 RWF ha^{-1})	Crop value (1000 RWF ha^{-1})	Net benefit (1000 RWF ha^{-1})
Bugesera				
1	4	149	248	99
2	5	95	225	130
3	6	64	265	201
4	4	440	257	-183
Burera				
1	3	242	399	156
2	3	281	340	59
3	10	365	599	235
4	12	428	612	184

Livestock Income

In Burera, farmers of Type 4 sell 75% and in Bugesera farmers of Type 3 and 4 50% of the milk, making profits of 50,000 RWF $year^{-1}$ in Burera and 180,000 to 295,000 RWF $year^{-1}$ in Bugesera. Animal products sold contribute much to the income of farmers, especially in Bugesera.

For individual farmers the income from animals increases with wealth as shown in Table 30. Whereas farmers of Type 1 in Burera and Bugesera gain 0 and 17,000 RWF $year^{-1}$ form yearly sales of animal products, farmers of Type 4 gain on average 41,000 and 121,000 RWF $year^{-1}$ respectively.

Table 30. Income from sales of animal products in RWF $year^{-1}$ and farm type

Farm type	Total income from animal products sold RWF $year^{-1}$	
	Bugesera	Burera
1	17,125	0
2	89,000	21,333
3	103,375	42,500
4	121,333	41,222

Off-farm Income

Other sources of income are very rare. Among the richer farmers (Type 3 and 4), one farmer receives a pension from the government, one owns a shop, one rents out a house and another receives remittances. Farmers of Type 1 rely on support of the government and NGO's who pay for health services.

Main off-farm income generating activities for resource poor farmers of Type 1 and 2 is working for other farmers. This activity is carried out part time when high labour demand is required in farming especially at the beginning of the growing seasons and for weeding, ridging, and harvesting. From this activity, farmers earn on average 89,700 RWF year^{-1} in Burera and 105,000 RWF year^{-1} in Bugesera.

In Bugesera, farmers of Type 3 and 4 earn on average 47,000 and 250,000 RWF year^{-1}, respectively, with banana and sorghum beer processing. Other activities, which were only practised by very few farmers, are brick and charcoal making and sowing.

3.3 Within-farm Variability

The analysis so far focused on the variability of bean farming systems across farm Types. In the following section, variability on the field scale within-farms is explored.

3.3.1 Field Distance

Earlier findings in East and Southern Africa suggest that fields with smaller distance from homesteads are smaller, managed more intensively, more fertile, and have higher yields (compare Tittonell et al. 2005 and Zingore et al. 2007). In the following, it is tested if that is true for the study sites.

The distance of fields from the homestead varies between sites from 2 to 2100 m and 2 to 5000 m in Burera and Bugesera respectively with similar average field distances of 334 m and 392 m (compare Table 5 for differences between farm types). Field sizes vary in Bugesera from 0.05 to 1.2 ha with an average of 0.15 ha. In Burera, field sizes are much smaller from 0.08 to 0.84 ha with an average of 0.11 ha. In both sites, no evidence is found for correlations between field distance and field size.

Farmers recognise differences in fertility, productivity, and suitability of their fields for certain crops. However, farmers' categorisation of soil fertility (very fertile, fertile, poor and very poor) did not correlate with field distance from homesteads. Correlations between field distance and soil fertility parameters are relatively weak and do not show a trend of decreasing fertility with increasing distance.

Field distance from homesteads hardly influences management (manure, crop residue allocation) except for staking of climbing beans. With increasing field distance of climbing beans, the proportion of Pennisetum stakes and stake height increase ($r = 0.55$ and $r = 0.43$, respectively).

Field distance from the homesteads does not influence crop productivity and has a small influence on crop allocation (Table 31). In Bugesera, swamp fields cultivated with maize and beans are located in large distances from the homesteads (up to 5 km). Pennisetum and potato fields are generally further away from the homestead because these crops are less prone to be stolen. Coffee and vegetables (tomatoes, cabbage, and leaf amaranth) are cultivated near the homestead because of their high economic value. In Burera, farmers cultivate all crops in all kind of distances except for sweet potato. Climbing beans are furthermore cultivated on relatively fertile and unfertile fields and on fields with steep slopes in contrast to crops such as potatoes.

Table 31. Average distance of fields cultivated with different crops for the two study sites

Crop	n	Distance from homestead to field (m)
Bugesera		
Coffee	8	141
Vegetables	5	151
Cassava	10	219
Fallow	7	232
Bananas	11	247
Groundnuts	7	256
Bush beans	14	309
Potatoes	5	534
Pennisetum	4	710
Maize	7	1625
Burera		
Sweet potatoes	2	132
Maize	18	214
Potatoes	9	294
Banana	2	384
Climbing beans	28	473

3.3.2 Landscape Effect

Since field distance and farm type have little effect on soil fertility variation, the effect of the landscape was explored. For Burera, which is characterised by especially heterogeneous topography, GPS coordinates of fields with the 20% highest (Max) and lowest (Min) measured soil parameters were plotted to compare visible clusters. It shows a clear landscape effect for organic C and sand content (compare Figure 10). Since organic C and total N correlate to 99%, total N shows the same landscape effect as organic C. The other soil parameters, e.g. P and K, do not show clear clusters, suggesting a less strong landscape effect on the studied scale.

In Bugesera, the landscape is more homogenous with no clear effect of the landscape except for the swamps with very fertile peat soil.

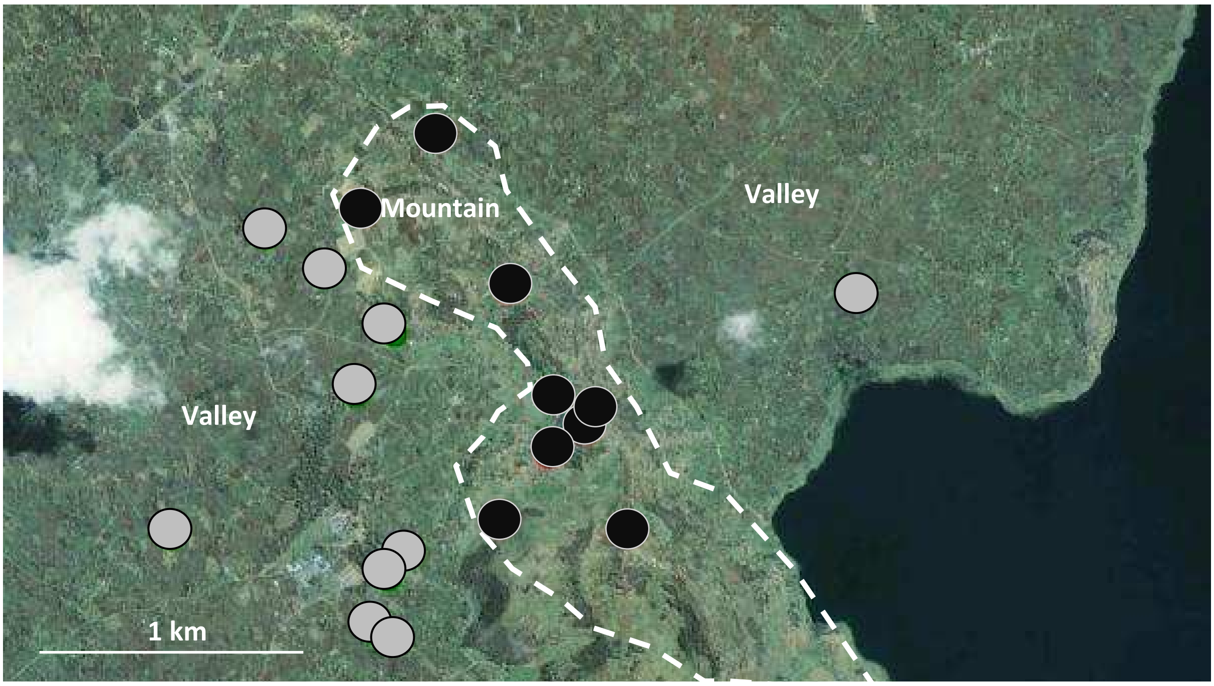


Figure 10. Spatial distribution of farmers' climbing bean fields in Burera with low and high organic C in 20% of the fields with lowest and highest measured values respectively (1.0-2.1% C_{org} and 6.6-8.2% C_{org})

3.4 Quantifying Climbing Bean Productivity and BNF

3.4.1 Productivity

Table 32 summarises the variables that influence climbing bean biomass and grain yield (two outliers of biomass samples and one of grain samples were removed). Manure application, soil available P and stake density and stake height effect above ground dry biomass yield. High biomass yields above 6 t ha^{-1} are obtained when farmers applied at least 5 t manure ha^{-1} (Figure 11 A) which translates only little into higher grain yields. The correlation of biomass production and soil available P is rather weak but higher P concentrations seem to increase biomass yield although low concentrations of 4 ppm P also lead to high yields of 6 t ha^{-1}. Stake density and stake height strongly influences biomass yield although little densities and height (20000 stakes ha^{-1}, 170 cm) still lead to relatively high yields.

Minimum and maximum boundaries of the N-fixation percentage indicate reduced grain yields with higher N-fixation (Figure 12 C). Numbers of nodules do not seem to influence biomass and grain yields (Figure 11 E) which may be an artefact of the low sample size of less nodulated plants, and nodule numbers may not be a good indicator for N-fixation.

Table 32. Statistically significant (α = 0.05) relationships with climbing bean grain and biomass productivity.

Productivity t ha^{-1}	Variable	r[a]
Biomass yield	Manure	0.78
	P	0.39
	Stake density	0.53
	Stake height	0.47
Grain yield	Stake density	0.73
	Stake height	0.58
	Mg	0.56
	P	0.60
	Ca	0.47
	CEC	0.52
	N-fixation (%Ndfa)	-0.52

[a] Pearson correlation coefficient (r)

Correlations indicate that stake density and height, N-fixation percentage and soil properties are important factors influencing climbing bean grain yield. There is a strong indication that stake density is an important factor influencing grain yield. Farmers achieving dry grain yields above 2 t ha^{-1} use a minimum staking density of 20 000 stakes ha^{-1} of an average height of above 170 cm per stake (Figure 12 A and B). Those achieving highest yields above 3 t ha^{-1} use more than 28 000 stakes ha^{-1} of an average height of above 200 cm per stake.

Higher input of labour (family and hired) does not necessarily lead to increased productivity (Figure 12 D). However, to achieve yields above 2 t ha^{-1}, at least 20 hours of labour per 100 m^2 are invested.

The soil fertility parameters P, Mg, Ca and CEC correlate positively with grain yield. Correlations with soil parameters in Figure 12 (E-H) include maximum boundary lines to indicate trends in the effect of soil parameters on grain yield. Available phosphorus, exchangeable Mg and Ca and the CEC correlate positively with grain yield. On fields with soil properties above 30 ppm of P, 3 cmol kg^{-1} Mg and 15 cmol kg^{-1} Ca, farmers harvest yields above 3 t ha^{-1}. Low concentration of Mg and Ca and a low CEC lead to low grain yields, but for available P, yields above 2 t ha can be obtained on fields with low concentrations such as 5 ppm (one sample was removed).

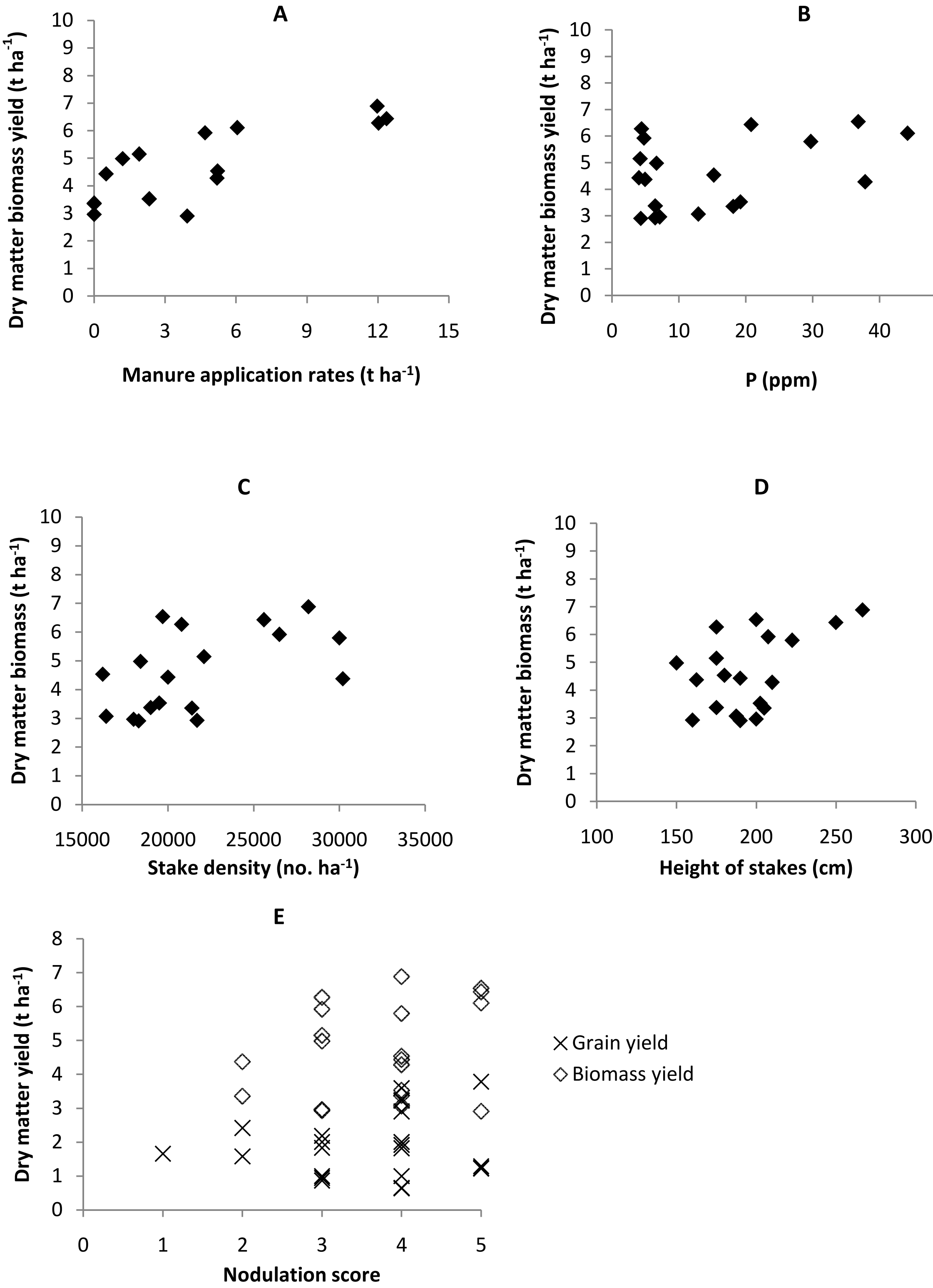
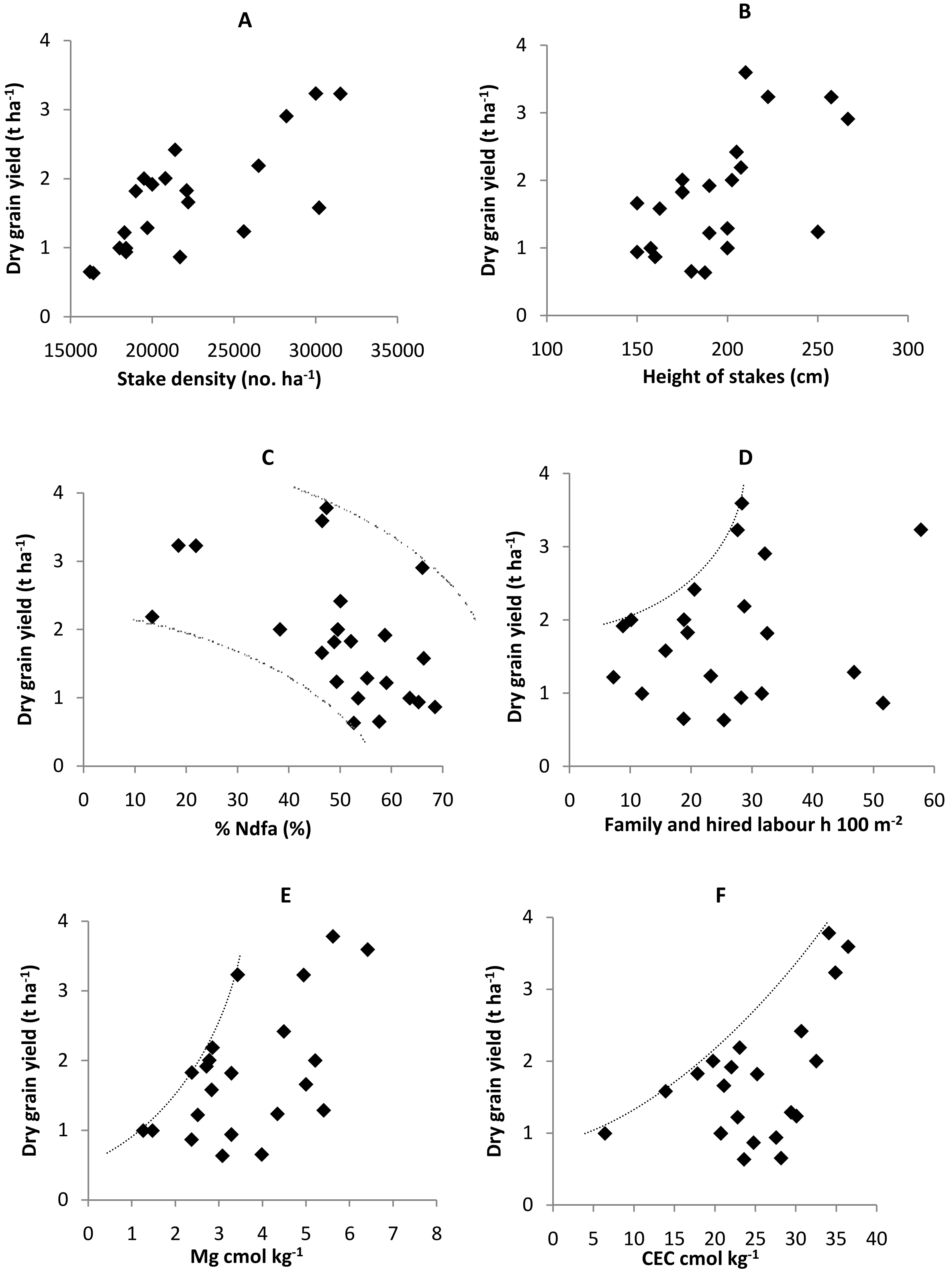


Figure 11. A The influence of manure application rates on dry matter biomass yield; B The influence of soil available P on dry matter biomass yield; C influence of stake density and D height of stakes on dry matter biomass yield; E influence of the nodule number (score 1 = <10; 2 = 10-20; 3 = 20-30; 4 = 30-50; 5 = >50) on above ground dry biomass and dry grain yield.


A
Dry grain yield (t ha-1)
0
1
2
3
4
15000
20000
25000
30000
35000
Stake density (no. ha-1)
B
Dry grain yield (t ha-1)
0
1
2
3
4
100
150
200
250
300
Height of stakes (cm)
C
Dry grain yield (t ha-1)
0
1
2
3
4
0
10
20
30
40
50
60
70
% Ndfa (%)
D
Dry grain yield (t ha-1)
0
1
2
3
4
0
10
20
30
40
50
60
Family and hired labour h 100 m-2
E
Dry grain yield (t ha-1)
0
1
2
3
4
0
1
2
3
4
5
6
7
8
Mg cmol kg-1
F
Dry grain yield (t ha-1)
0
1
2
3
4
0
5
10
15
20
25
30
35
40
CEC cmol kg-1

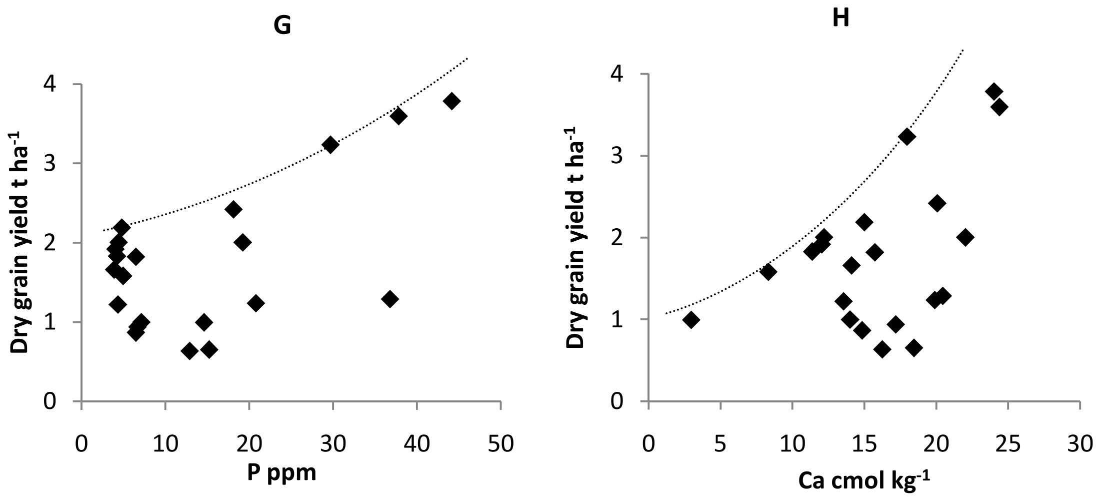


Figure 12. A The influence of stake density and B height of stakes on dry matter grain yield; C influence of N derived from the atmosphere on dry matter grain yield; D influence of family and hired labour inputs on dry matter grain yield; E-H influence of selected soil properties (Mg, CEC, P and Ca) on the dry grain yield.

3.4.2 Biological Nitrogen Fixation

Table 33 summarises the performance of biological nitrogen fixation (BNF) in farmers climbing bean fields as measured with the natural abundance method (data is reported in Annex 7). Climbing beans derive 13% to 66% N from the atmosphere, with an average of 50%. Two fields, where the measured N derived from the soil exceeded the estimated N supply from the soil were removed. The N-fixation rate is on average higher in bean pods (55%) than in bean shoots (46%). Relative N-fixation in the bean roots is assumed to equal relative above ground fixation. The number of active nodules could not explain variability in the N-fixation rate across fields. The few fields assessed with plants with less than 20 nodules show still high fixation rates of >45% N.

Table 33. Percentage and absolute N_2-fixation in 23 climbing bean fields in Northern Rwanda.

N_2-fixation	N recovered in crop (kg ha^{-1})			N fixed (kg ha^{-1})			% Ndfa (%)		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Pods	43	6	101	23	3	68	55	10	78
Shoots	105	27	228	47	9	123	46	7	65
Roots (estimated)	49[b]	13[b]	92[b]	23[b]	6[b]	49[b]	50[a]	13[a]	66[a]
Total[c]	196	52	372	93	23	199	50	13	66

[a] Assumed to equal above ground fixation percentage, [b] Assuming that root N equals 33% of above ground plant N, [c] Based on a weighted mean (compare Chapter 2.5)

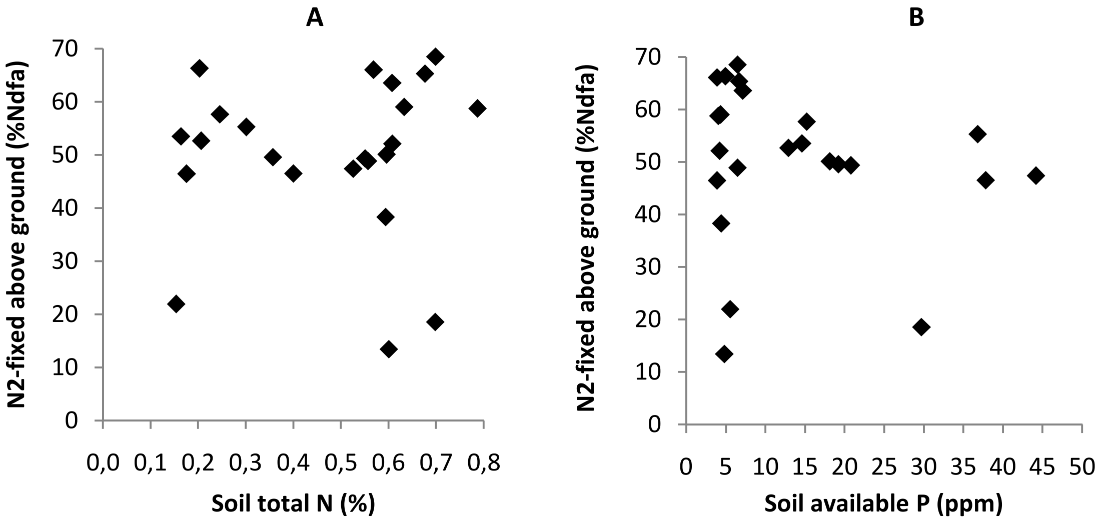


Figure 13. The influence of (A) soil total N and (B) soil available P in the soil on the N-fixation rate.

Decreasing N-fixation rates with increasing yield (Figure 11 E; Figure 12 C) suggests that plants with higher productivity derive more N from the soil either by higher uptake efficiency or due higher total N concentrations in the soil. The latter is unlikely since no correlation could be found between N-fixation and soil total N (Figure 13 A). The concentration of soil available P also does not influence N-fixation rate (Figure 13 B). Increased uptake efficiency might be influenced by a better developed rooting system.

Farmers' management (amount of manure applied, the variety selection, spacing, and number and height of stakes) hardly affects the variability observed in N-fixation rate. No effects on N-fixation could be found by soil parameters.

N-fixation above and below ground (N-fixed kg ha^{-1}) is determined by the production of plant biomass and the %Ndfa and ranges from 23 kg to 199 kg N ha^{-1} with a mean of 93 kg N ha^{-1}. N-fixation below ground assumed that root N equals 33% of above ground plant N. Pods were in the early filling stage and not mature during harvesting, which resulted in higher N-fixation in the shoots (47 kg N ha^{-1}) compared to the fixation in the pods (23 kg N ha^{-1}).

Variations in N-fixation can mainly be explained by the variation in biomass yield, which is caused by farmers' management (manure application rates and no. and height of stakes) and a minor soil fertility effect (P). No evidence could be found for correlations between N-fixation and dry grain yield.

3.4.3 Partial Nitrogen-Budgets

Different partial nitrogen budgets were calculated , taking total above and below ground N-fixation into account (Figure 14 A). All scenarios neglect the N returned to fields in animal manure after feeding bean residues and N losses during the mineralisation of residues in the dry season (farmers incorporate CR with the land preparation for the next crop, there are no animals which feed on CR retained on fields). Besides, additional N inputs such as wet and dry atmospheric deposition and N outputs e.g. through leaching, (de)nitrification and volatilisation are neglected as well.

Scenario 1 simulates farmers' practises where all grain is harvested, no residues of the pods are returned, and all shoots and roots remain in the field. This budget results in a mean positive N balance across fields of 50 kg N ha^{-1}. The variation across farmers' fields is very large ranging from -26 kg to 147 kg N ha^{-1}.

Scenario 2 assumes that all grain and all residues are removed and only roots remain in the field. This budget results in a mean negative N balance of -55 kg N ha^{-1}. For all fields balances remain negative, ranging from -13 kg to -158 kg N ha^{-1}.

Scenario 3 calculates with different proportions of crop residues left on the field, based on farmers' actual crop residue management for the specific field. Depending on farmers' bean residue management, these partial N-budgets per field ranged from -80 to 45 kg N ha^{-1} (with a mean negative N balance of -15 kg N ha^{-1}).

As shown earlier, farmers of different farm types remove different amounts of CR from their fields to feed their livestock. Resource poor farmers (Type 1) remove much higher amounts of CR from their field than resource rich farmers (Type 4) since they lack alternative feed sources such as pennisetum. Figure 14 B shows that resource poor farmers have an average negative partial N-budget of -43 kg N ha^{-1} (all fields have a negative budget) and wealthier farmers, who retained part of the residues on some of their fields, had positive and negative N-budgets. Resource rich farmers have an average N balance of -3 kg N ha^{-1}.

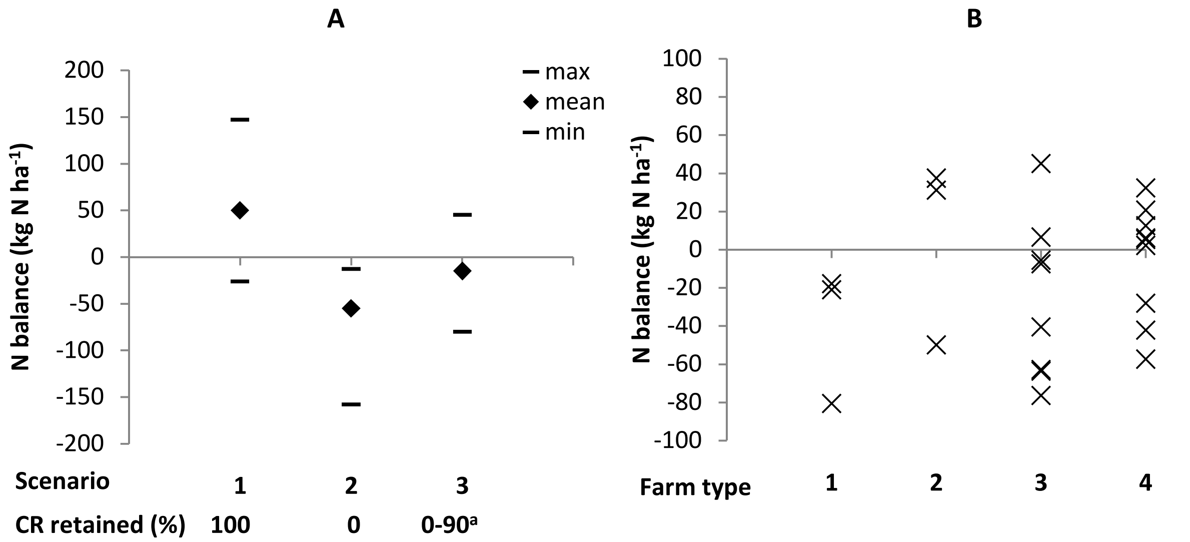


Figure 14. (A) Partial N-budgets for climbing bean fields in Burera considering above and below ground N_2-fixation of three scenarios of crop residue management (1 = 100% CR retained; 2 = 0% retained; 3 = 10-90% retained), (B) Farm type effect on partial N-budgets with varying CR management (scenario 3).
[a] Depending on individual farmers' practises, calculated per field separately.

4. Discussion

In the discussion, the different chapters of the results will be discussed and the research questions answered. As a conclusion, the potential niches for grain legume intensification will be identified.

4.1 Farming Systems Characterisation of Different Farm Types

In the first section, the first two research questions 'What is the role of beans in the farming systems and what are current bean farming practises in the two study sites, as influenced by farm and field types?' will be answered. Based on this analysis and by comparing the Ubudehe typology with other farm typologies, the second research question 'Can the Ubudehe household typology be used as a farm typology?' will be addressed.

4.1.1 The Role of Beans

Beans play a major role in Rwandan smallholder farming systems and are the main staple food crop in the country. Relative to other crops, beans are cultivated on a large share of the farmland (Table 34). In Bugesera, generally a larger diversity of crops is cultivated than in Burera resulting in a smaller share of beans. Labour inputs and crop production costs of beans are relatively low in Bugesera and relatively high in Burera (although much lower than for potatoes). Stakes contribute much to the higher labour requirements and higher production costs. The partial budget analysis based on data from farmers estimates of inputs and outputs indicate that net benefits are highest in groundnuts (Bugesera) and potatoes (Burera) and are negative for bush beans and relatively high in climbing beans. Calculations are based on farmers' estimates and due to a high variability in net benefits between seasons, the presented results provide an indication of the performance between crops. The nutritional value of beans in terms of proteins is in both sites very important relative to other crops. In Bugesera, low grain yields lead to a low energetic production. Climbing beans have a high energetic yield (comparable to maize but below that of potatoes) and the highest protein yields.

Table 34. Crop production costs, crop value, net benefits, and nutritional value of selected crops (870 RWF = 1 EUR; 1 kcal = 0.004 MJ)

Crop species	Area per farm (%)	Labour input (h ha^{-1})	Crop production costs (1000 RWF ha^{-1})	Net benefit (1000 RWF ha^{-1})	*Energy (MJ ha^{-1})*	*Protein (kg ha^{-1})*
Bugesera						
Groundnuts	4	4 104	439	571	19 274	210
Maize	4	2 376	205	243	38 953	245
Cassava[a]	21	3 784	161	106	29 842	46
Bush beans	14	1 762	263	-14	10 748	193
Potatoes	5	1 275	408	-119	5 369	32
Burera						
Potatoes	5	4 268	671	1 112	39 822	238
Climbing beans	40	2 786	369	186	23 937	429
Maize	22	2 081	250	31	22 929	144

Source: Annex 4; [a] For the whole growing cycle, cassava is intercropped with other crops

Beans are cultivated for human consumption and for marketing. In climbing beans, farmers mention the high yields as important and the utilisation of fresh and dry plant parts for consumption. CR as animal feed are important especially for resource-poor farmers but this is a secondary reason to grow beans. Farmers do not grow beans specifically to increase soil fertility, although farmers in Burera perceive yield increasing effects in the crop succeeding climbing beans.

As shown under 3.2.1 the decision to grow beans is not only influenced by farmers' preferences but also by agronomic potentials and socio economic conditions including institutional support and barriers. Agronomic limitations of crops (e.g. drought sensitivity of soy bean and bush bean) and institutional influences e.g. the policy on land consolidation (supporting bush beans and maize and excluding sweet potato) are important drivers for farmers to increase, decrease or abandon crops. Farmers increase and decrease the cultivation of certain crops between years depending on market prices, diseases and weeds (e.g. striga infestation in sorghum or root rot in beans), environmental conditions (e.g. due to recent droughts farmers increase the cultivation of groundnut and cassava) etc.

The dilemma here is that abandoned crops cannot always easily be re-introduced if seed material is not available in adequate quantities e.g. sweet potato in Bugesera, which has also been reported a constraint in Eastern Uganda (Abidin 2004). The reported crop failure of bush beans in the season 2011A due to rainfall deficits in November and December could lead to drastically reduced area of bush beans in the next year. Instead, the cultivation of more drought tolerant crops is likely, which could create an agronomic niche for groundnuts.

The study demonstrates that bean farming practises vary much across the Ubudehe farm types and between the study sites. To answer therefore the first research question 'What are the current bean farming practises' these will be characterised for each farm type.

4.1.2 Bean Farming Practises Across Farm Types

In Eastern and Southern Africa, farm typologies have been widely used to characterise differences in resource endowment and farming practises across different farm types e.g. in Rwanda (Bidogeza et al. 2009 and Ansoms and McKay 2010), Western Kenya and Eastern Uganda (Tittonell et al. 2005 and 2010) and in Zimbabwe (Zingore et al. 2007).

The farm typology developed by Tittonell et al. (2005 and 2010) for Eastern Uganda and Western Kenya is the most extensively documented in East Africa and concentrates on farming practises. Tittonell et al. distinguish between five farm types based on resource endowment, dependence on off-farm income, market orientation, and food self-sufficiency (Figure 15). The Ubudehe farm typology is based on the same criteria. However, compared to the typology by Tittonell et al., the studied farms in Rwanda show stronger differences across farm types (difference in farm size, number of livestock, input use etc.). These differences across types are much more visible in Burera where farmers are more resource constrained compared to Bugesera. Whereas farms of different farm types in Bugesera have comparable farm sizes relative to farms in Western Kenya or Eastern Uganda, in Burera, there is an indication that farmers are more land constrained (compare Tittonell et al. 2010) although population densities are higher in some sites of Western Kenya.

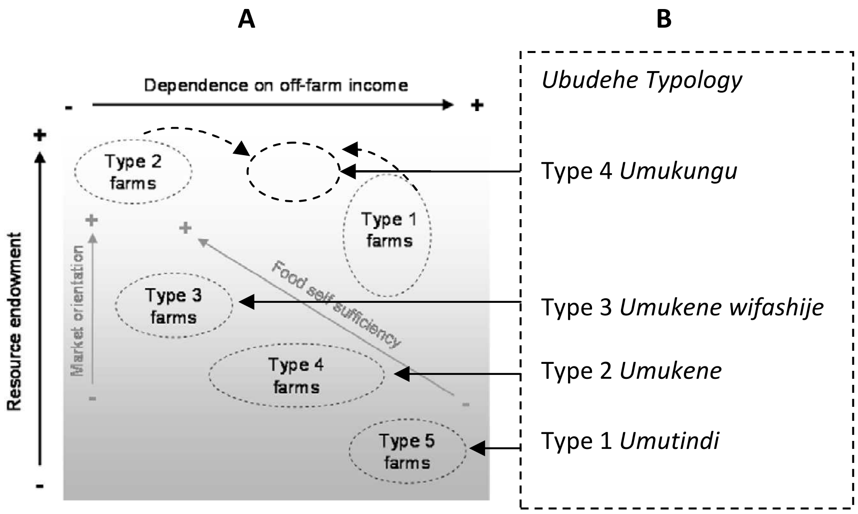


Figure 15. The proposed farm typology, from (A) a multidimensional approach considering the main source of income and production orientation. The intensity of shading roughly indicates of the distribution of households in a community. The farm types are encircled in dotted lines indicating that there are no actual clear-cuts between types. (B) shows the corresponding Rwandan farm types. (after Tittonell et al. 2010, p. 95)

The largest differences across farm types are found between the very resource-poor, the *Umutindi* category (farm Type 1) and the resource rich, the *Umukungu* category (Type 4). Between the farmers of Type 2 (*Umukene*) and Type 3 (*Umukene wifashije*) lies the transition between the resource-poor and the resource-rich. These two farm types together are the most common in rural Rwanda, representing 76% of the population in the studied cell in Burera and 89% in Bugesera.

The resource-poor farmers of the typology by Tittonell et al. correspond with the Ubudehe farms of Type 1 (Figure 23). They are in both typologies very resource-poor self-subsistence oriented, not food sufficient and mainly land constrained. These farmers, grow a very low diversity of crops and beans are cultivated on 50% and 24% of their land in Burera and Bugesera, respectively and are crucial for home consumption. To feed their livestock, they rely on (bean) crop residues. Farmers own fields only near their homestead. No indication can be found that these fields are more fertile compared to fields of resource rich farmers which own fields near the homestead and far away. This differs from the arguments by Ansoms (2008) who reports higher soil fertility on fields of resource-poor farmers and the findings by Tittonell et al. (2005) who measured higher fertility in fields near the homesteads. In bean fields, the lack of resources leads to little application of animal manure, the use of few and short stakes (in climbing beans) and a limited amount of labour. The lack of sufficient inputs, results in lower mean grain yields of climbing beans of 1.2 t ha^{-1} compared to mean yields of 2.27 t ha^{-1} of farmers of Type 4.

In case of the resource-rich farmers, Tittonell et al. distinguish between the farming oriented and the off-farming oriented (compare Figure 15). In the Ubudehe typology, this distinction was not found and farms of Type 4 are both, farming and off farming oriented. Like the farming oriented farm type by Tittonell et al., they have large farmland available relative to other farmers and the capital to hire land, to grow cash crops and to keep larger numbers of livestock. In Bugesera, such farmers have several bean and maize plots in the land-consolidated swamps. They compensate the lack of labour (highlighted by Tittonell et al. as main constraint) with permanent hired labourers. Farmers grow the largest diversity of crops for the market and for home consumption. Beans occupy around 25% and 10% of the farmland in Burera and Bugesera, respectively, of which one third is consumed. As reported by Tittonell et al., such farmers use more farm inputs e.g. in Burera, the double of labour hours for crop production compared to farmers of Type 1, a higher density, and height of stakes and apply more animal manure. A few farmers even apply DAP fertiliser (in very small doses) and insecticides (especially in season B). Due to their market orientation, they cultivate pennisetum for fodder and stakes and allow most bean residues to remain on the field, leading to neutral N-budgets frequently. The keeping of seed ensures its quality and independence from the seed market. Comparing the bean farming profitability (considering labour opportunity costs) this is not higher compared to resource-poor farmers and even negative in Bugesera, due to high input costs (hired labour). Farmers might cultivate beans due to cultural and nutritional preferences but it remains unclear, why farmers still grow the crop for marketing and if this might change in future if the profitability remains low. Their farming and off-farming orientation make farmers of Type 3 and 4 the wealthiest households in both sites.

For the most common farms in both areas, Ubudehe farm Type 2 and 3, beans also play an important role accounting for around 40% and 10% of the farmland in Burera and Bugesera, respectively. Like the medium resource-poor farms by Tittonell et al., farmers of the Ubudehe Type 2 have little available resources (although more than those of Type 1) and are rather subsistence and only very little market oriented. They sell around one third to half of their produce although they are not food-sufficient and keep part of the seed needed for the next season. Farmers of Type 2 permanently work for other farmers (same as in Western Kenya) and in contrast, farmers of Type 3 do not work for others but employ labour occasionally. These invest more in farming inputs and are more market oriented and food-sufficient (same as by Tittonell et al.). They produce almost double the food (GFP) of farmers of Type 2 due to a larger farm size and higher productivity (GFY). Climbing bean grain yields are much higher with 2.02 t ha^{-1} (Type 3) compared to 1.14 t ha^{-1} (Type 2). The net benefit is on average 82% higher in farms of Type 3 if opportunity costs are included.

In Bugesera, the two farm types (Type 2 and 3) are sometimes more difficult to separate due to similar household assets (farm size, number of livestock, quality of housing etc.) although their wealth status is clearly different underlined by their food security status and the labour allocation.

Tittonell's farm Type 1 was not found within the studied sample. People with a fixed salary or pension are rare in rural Rwanda but might emerge in the near future due to the increased economic development of the country.

Between Sites

This study shows a stronger variation within farm types in Bugesera compared to Burera. This might be the case due to a shorter tradition of farming in this area which was used by pastoralists before (farmers migrated 20-40 years ago; compare 3.1). Farmers cultivate a larger diversity of crops, which might be a strategy of spreading risks of crop failures, but might also be a sign that farming systems are not fully developed yet and the most suitable crops not yet identified. This is supported by no fixed crop rotations in Bugesera and the little knowledge of farmers on rotational effects.

Other differences between both sites are the crop residue management. Whereas resource-rich farmers in Burera maintain the residues in the field with the intention to increase soil fertility (farmers are aware of the positive rotational effects), farmers of the same category in Bugesera remove the residues as feed and for bedding material and are also not aware of the positive rotational effects if crop residues are kept in the field.

Farmers in Bugesera are generally more market oriented irrespective the lower market access in the region and even farmers of Type 1 sell 20% of their produce.

The higher agro-ecological potential in Burera and an exceptionally high population density of 524 people km^{-2} leads to a generally higher food production per unit area (GFY) across all farm types.

In Burera, the availability of bean seed is problematic especially for poorest farmers since they consume all because of being food insecure. Therefore, they rely on purchasing seed of varying quality and have no access to improved varieties, or control on which variety they purchase. They can therefore not choose varieties that are especially useful for resource-poor farmers e.g. varieties of which fresh plant products can be consumed (compare Annex 5). This also affects the distribution of seeds through donations e.g. through

N_2AFRICA. To enable these farmers to have access to improved seed continuously, they need to be offered at a local level for the same costs as non-improved varieties. Another option could be that wealthier farmers (who keep seed) are given incentives to sell seed to the resource poor farmers in their neighbourhood or association.

Farmers' climbing bean yields are much higher than previously reported by CIAT (CIAT 2008) and Burleigh et al. (1992). High yields are obtained although hardly any synthetic fertilisers are used although this is suggested to be necessary by ISAR to obtain high yields (ISAR 2010). Besides, the density of stakes used in farmers' fields is much lower than recommended by ISAR, who recommend densities of 50 000 stakes ha^{-1} in single staking (ISAR 2010). In contrast, farmers use 16 000 to 32 000 stakes ha^{-1} in single staking. This highlights that farmers´ management practises can differ much from the perception of scientists and still lead to high productivity. Detailed farming characterisations are needed and can bring farmers practises and scientists perceptions together.

Ubudehe as Farm Typology

Whereas the studies by Tittonell et al. (2005 and 2010), Zingore et al. (2007), Bidogeza et al. (2009), and Ansoms and McKay (2010) developed farm typologies based on methods chosen by researchers, this study builds on an existing household typology developed by the Rwandan government. For the first time, this study shows that the Ubudehe typology can be used for agricultural research to stratify farms according to the resource endowment with regional specific indicators.

Working with this typology helps to communicate the results and recommendations to national policy makers and agricultural researchers, consultants and other stakeholders.

Although farmers of different farm types have very different constraints and demands, farmers should not be seen separately due to strong interconnections between farmers of different types. Some examples are the resource poor working for the resource rich and trading of food amongst farmers. If interventions aim at targeting certain farm types, the relationships between the different types need to be taken into account and can be used to support the implementation of interventions. An example for this is the current seed system. Resource-rich farmers who keep improved variety seeds (e.g. supplied by development programs) for next seasons need to be involved and receive incentives in order to make such seed constantly available to resource poor farmers who do not keep the seed. Such incentives could be that they receive improved varieties at no costs or resource-poor farmers exchange a specific amount of their labour force against the improved seed.

4.1.3 Exploring the Existence of Common Field Types

Studies show that farmers can classify their fields according to soil fertility (e.g. Pletsch-Betancourt 2001, Tittonell et al. 2005), resource allocation and productivity (Tittonell et al. 2005). In this study, farmers classification is only very little correlated with soil fertility parameters and not with productivity and resource allocation. Since farmers could only classify the fields relative to their own fields, no standardised scale can be assumed between farms, which limits the possibilities of comparisons across farms. Tittonell also has noted this (2003 p. 41). In the study of Pletsch-Betancourt (2001), farmers classified the soil fertility status of different fields according to different soil types (using their local terms) which might be more useful for comparisons than a scale of fertility. Such a classification rather gives an indication on which fields farmers cultivate crops according to their perceived fertility. This highlights that bush and especially climbing beans are cultivated on all kind of soils from 'very fertile' to 'unfertile' (the latter are fields with severe slopes). Statistical analysis also underline that climbing beans are cultivated on fields significantly lower in organic C and total N than potatoes which are not cultivated on 'unfertile' fields.

In Burera, the concentrations of organic C, total N and sand could not be explained by management but landscape effects e.g. fields on the hillsides had lower organic C concentrations. Thus, the position of the farm and fields is important, which depends on various historic and institutional factors and is not correlated with specific farm types or wealth. The ‘landscape effect’ is in case of the mentioned parameters stronger than management factors (resource allocation).

Detailed studies in Western Kenya (Tittonell 2003 and Tittonell et al. 2005) and Zimbabwe (Zingore et al. 2007) provide evidence for within-farm soil fertility and management gradients between fields. Authors distinguish between four different field types: Home fields, close fields, mid-distance fields and remote fields. In this study, resource allocation, productivity and soil fertility across fields was explored in detail but no evidence found for soil fertility gradients as a function of distance of fields from the homestead. The high population density and land scarcity in Rwanda (especially in Burera) is likely to be the cause why farmers manage all available farmland intensively irrespective of the distance from their homestead and perceived land quality. Tittonell et al. 2005 could identify such soil fertility gradients based on field distance from the homesteads and farmers perceived land quality. However, they found that ‘in a densely populated locality (...), the magnitude of within-farm soil fertility gradients tended to be smaller than in the other sites’ (p. 181).. Besides, the relatively low livestock densities in both Rwandan sites compared to Western Kenya and Zimbabwe, is likely to be an important factor for low fertility gradients through nutrient transfers by animals. The zero-grazing systems in Rwanda furthermore reduce such nutrient transfers.

4.2 Climbing Bean Productivity and BNF

In the second section, the variability of climbing bean productivity, BNF performance, and N-budgets will be discussed to answer the third research question ‘How productive are climbing beans (in Northern Rwanda) in farmers’ fields and how much nitrogen do they fix? Which factors influence the productivity and nitrogen fixation?’.

Productivity

Climbing bean grain yields measured in farmers’ fields are relatively high with 1.97 t ha^{-1} on average and maximum yields of 3.6 t ha^{-1}. In a study conducted in Northern Rwanda in 26 farmers’ fields in 1988, Burleigh et al. (1992) measured a lower average climbing bean yield of 1.53 t ha^{-1} with similar variations between 0.1 and 3.18 t ha^{-1}. Wortmann measured average climbing bean yields of 2.14 t ha^{-1} over 3 years under controlled conditions in fertilised and well managed on-farm trials in South Western Uganda (100 km from the study site with similar agro-ecological conditions). Much higher yields are reported by Kumarasinghe et al. (1992) in Italy and Francis et al. (1978) at CIAT in Columbia under optimal growing conditions of 4.7 t ha^{-1} and 3.5 t ha^{-1} respectively.

Up to date, no detailed yield data of climbing beans in farmers’ fields were documented for Rwanda. The CIAT newsletter reports yields of 0.6-1.1 t ha^{-1} in farmers’ fields (CIAT 2008). Potential yields of the improved varieties are provided by ISAR in the variety descriptions of the newly released varieties (in 2010). For the variety Gasirida, the potential yield is stated to range from 4 to 5 t ha^{-1} (ISAR 2010). The recommended agronomic practices provided with the variety description of ISAR are to plant 20 plants m^{-2}, to apply 30 t ha^{-1} of farm yard manure and to use a density of 50 000 stakes ha^{-1} of 2-3 m length. This study shows that farmers achieve relatively high yields (with high variations) using plant density similar to the recommendations but by applying much less manure and stakes.

Main variables measured in this study and correlating well with grain yield were the density and height of stakes and specific soil fertility parameters (especially P, Mg, Ca and CEC). This gives an indication that management has a strong influence on yield because of the staking and the soil fertility parameters were shown to be influenced by management (e.g. manure application) and not by inherent landscape effects (such as organic C and total N). This explains higher productivity in farms of resource-rich farmers.

Although manure application rates was not strongly correlated with grain yield, manure might still play an important role, which was difficult to measure. Manure application per field differs much between seasons and years, which could not be captured in this study. However, manure application in the studied season had an effect on biomass yield, which was not translated into higher grain yields but higher total N-fixation. These findings are in line with the farmers' perception on how to increase productivity who state the quality of stakes, amount of organic manure and good agronomic practises as the main prerequisite.

Biological Nitrogen Fixation and N-Budgets

The measured N-fixation rate (%Ndfa) of on average 50% is comparable to the measurements by Wortmann (2001) of 58% Ndfa who studied climbing bean-sorghum rotations under controlled and fertilised conditions in South Western Uganda (using the natural abundance method and a little lower B value of -1.97). The study by Kumarasinghe et al. (1992) in Italy reports higher fixation rates of 66% Ndfa (under optimal growing conditions, with fertilised and inoculated climbing beans). The studies do not report any minimum and maximum values that could be used to compare the range of N-fixed ha^{-1} with the values measured in Rwanda. Although, the N-fixation percentage of climbing beans appears relatively low, they fix high absolute amounts of around 100 kg N ha^{-1} above and below ground due to high biomass yields (5 t ha^{-1}).

This study reports large variations in N-fixation (13%-66%) which is difficult to explain and might be a cause of the accuracy of the natural abundance method including the choice of the reference plants. For verification of this method, it should be coupled with other methods. However, the variation in N-fixation might be a result of genetic variation in N-fixing potentials of the germplasm (Graham 1981 and Bliss 1993) and environmental and management effects which could not be identified in this study (besides a trend of lower N-fixation rate with increasing grain yield). Giller (2001: 164) also reports high variations in N-fixation in a review of four studies with 0-73% Ndfa and 2-125 kg N ha^{-1}. He explains low fixation with poor nodulation of *P. vulgaris*, which has often been observed in farmers' fields in the tropics (Giller 2001: 157). Ojiem et al. (2007) also found large variations in N-fixation rates in on-farm experiments with bush beans, ranging for one study site from 12% to 48% Ndfa. This study collected data from heterogeneous farmers' fields of different resource endowment categories and management practises, which might explain part of the high N-fixation variability. It remains unclear, which specific factors influence the N-fixation rate. However, absolute N-fixation is shown to be much influenced by the biomass productivity.

This study shows that in the early pod filling stage, the shoots contain the majority of aboveground plant N, which has also been found in other studies e.g. Kumarasinghe et al. (1992). Therefore, the farmers' management of bean crop residues and feeding practises have a large effect on N-budgets. These are positive if only pods are removed and CR retained or nutrients returned to fields. N-budgets are negative for all fields if pods and all CR are removed and no nutrients returned. The actual farmers practise is however in between and results in positive and negative balances.

Under similar farming conditions, Wortmann (2001) shows that highest productivity of climbing bean-sorghum rotations are obtained when only bean pods are removed or bean crop residues are returned to fields. N-budgets calculated by Laberge et al. (2008) for soybean show similar effects of the crop residue management. If all residues are removed, N-budgets are close to zero, if manure from animals (who received the CR as feed) is returned, this results in positive budgets of 10 kg and 95 kg N ha^{-1} at two different sites.

The calculated N-budgets are partial and do not consider all N in- and outputs. If fields are fertilised with animal manure and mineral fertilisers, average N inputs under current farming conditions are estimated as

30 kg N ha^{-1} yr^{-1}. Wet and dry atmospheric N deposition can be estimated as 13 kg N ha^{-1} yr^{-1} (Adon et al. 2010). N outputs, such as N leaching can account for losses of up to 140 kg N ha^{-1} yr^{-1} in the East African highlands (Shepherd et al. 1996). Depending on the nutrient inputs through fertilisation and the amount of N leaching per field, N budgets in Northern Rwanda are likely to be much more negative than calculated in this study and will differ much between farm types.

In Bugesera, resource poor farmers rely less on crop residues as animal feed (feed only around 10%) and retain more CR on their fields than farmers in Burera which could lead to positive N-budgets.

As a conclusion, climbing beans reduce N deficits through N-fixation but hardly contribute to the N demand of the next crops. Positive balances dependent on the N-fixation rate (influencing factors remain unclear), the biomass productivity (influenced by stakes and manure) and the bean residue management (influenced by other feed alternatives).

4.3 Niches for Intensification

The identification of possible niches to intensify bean cultivation and the resulting trade-offs are elaborated and the fourth research question 'Where are niches for intensified bean cultivation for the different farm types?' will be answered.

The overall goal for the identification of niches to intensify bean cultivation in Rwanda is an increased food sufficiency of rural households and to utilise commercial opportunities. To achieve this, it is assumed that intensified bean cultivation reduce the bean deficit by providing sufficient beans for consumption, feed to animals and increase soil fertility.

In order to identify a niche of a crop, its multiple purposes need to be considered. Beans are cultivated for cash (grain), food (grain, leaves and pods), and feed (crop residues). Its potential to fix N and to increase soil fertility is not a major reason for farmers to grow the crop but needs to be considered for the identification of the niche. Different uses can be complementary but also lead to direct trade-offs (Giller 2001: 294) especially for the use of crop residues (feed vs. soil fertility).

Furthermore, the 'multi-dimensional' character of the niche for grain legumes need to be considered according to Ojiem et al. (2006). This includes agro-ecological, socio-cultural, economic and local-ecological factors which together form the 'socioecological niche' (Ojiem et al. 2006).

Intensification can be achieved by a larger area cropped under beans or through an increased productivity of the already grown areas. The increase of the area under beans is argued to be often neglected in tropical cropping systems (Giller 2001: 294).

Increase in Area

This study shows that already large proportions of the farmland are cropped under beans; on average 40% under climbing beans in Burera and 14% under bush beans in Bugesera. In the latter site, 4% of the farmland is cultivated with groundnut accounting for a total grain legume cultivation of 18%. In both sites, the relative share of beans is higher for resource-poor farmers although the absolute share is still much lower compared to resource-rich farmers.

In Burera, climbing beans were introduced relative recently (in the 1980s) and became the major crop in the area until now. The introduction of climbing beans is a case where a niche was successfully identified and filled. The agro-ecological, social, and economic factors were all suitable for introducing climbing beans. Currently, all farmers grow climbing beans on large proportions of their land providing little space for an area increase. Climbing beans are cultivated on all fields including those far from the homestead, low in soil fertility and on steep slopes, i.e. no currently neglected niches for additional bean cultivation exist.

In Bugesera, the area under grain legumes is at risk to decrease due to environmental stress (drought). Soybean has recently already been abandoned by the studied farmers due to low performance under drought conditions and little marketing options. Beans are still grown on 14% of the farmland. A strategy is therefore urgently needed to stop further decreases of beans and the abandoning of soybean in farms who still cultivate it. The underlying reasons for the decrease were mentioned in this study and the constraints form a niche for interventions with suitable bean technologies. Options could include growing beans on the fields with the highest water holding capacity (WHC) near the swamps. However, resource poor farmers often do not have fields high in WHC and resource rich farmers grow preferably vegetables on such fields. Another niche within the farm is intercropping beans within banana plantations (which is already practised by some farmers) and the cultivation on former banana plots.

The niches for beans are rather limited due to the environmental constraints. A crop that is increasingly cultivated by farmers is groundnut. There is a niche in the farming system for groundnut because it can cope with the environmental conditions due to its drought tolerance and there is a high demand for groundnut on the market. High yields and high prices on the market lead to very high net returns exceeding all other annual crops in Bugesera. Groundnut grows within the farm also on fields with a low WHC and can be intercropped with other crops such as coffee, banana, or cassava. Farmers are likely to increase the cultivation of groundnut in future, which will most likely lead to the replacement of crops which are less drought tolerant, including beans. However, Rwandan farmers consider the food value of groundnut lower relative to beans. Farmers could compensate this by buying beans from the sales of groundnut. The effects of increased groundnut cultivation in Bugesera on the price elasticity, the net returns, availability of crop residues as animal feed, and the performance of BNF remain unknown.

Intercropping beans with cassava is currently not a common practise in Bugesera but shows elsewhere higher economic returns than a single crop. The purpose of such intercropping is to use the light interception more efficiently. In South Kivu of the DRC, Pypers et al. (2011) show that with a modification of the crop arrangement of a cassava-bean intercropping system, this permits a second bean crop leading to high yields and additional revenue. However, cassava currently is grown on very sandy and rocky soils with a low WHC, which makes intercropping with beans difficult. Groundnut could provide more options and better results as a cassava intercrop, which requires further assessment.

Niches for beans are currently the ‘land consolidated’ swamps in season C where beans are grown every second year (alternating with maize), as predetermined by government policy. Farmers of all farm types can apply for a plot in the swamps and have therefore theoretically access to this niche. In reality, resource-poor farmers do not have enough labour available to cultivate the fields in the swamps which are often far away from the homesteads. Furthermore, the policy does not allow own consumption of leaves, fresh pods or grain, on which these farmers rely. The policy is likely to lead to lower market prices through the large-scale production, which benefits the urban population more than the rural farmers (similar effects are reported by Ansoms 2008).

Increase in Productivity

Intensification of the productivity of bean farming systems is the most suitable approach to increase benefits from bean cultivation. This study shows large differences of bean farming practises and constraints calling for different intensification strategies for different farm types.

In Burera, the availability of staking materials is the most limiting resource to the current climbing bean production. Especially resource-poor farmers of Type 1 and 2 have very little access to stakes, which is likely to contribute to the low yields they achieve. A strategy is needed to test and provide alternative staking methods (to reduce the number of stakes needed e.g. through combinations with strings and stakes or metal stakes which can last for many years) and to increase the access to stakes. Although farmers of Type

3 and 4 have better access to stakes and use relatively high densities, they still use rather short stakes which is likely to limit the productivity. An institutional approach is required here including various actors and authorities of natural resources including forestry, to communicate the scarcity of stakes and find suitable solutions for the near future e.g. by forming linkages with reforestation programmes. Density and height of stakes were strongly correlated with yield. Staking quality might limit other technological improvements as well, such as improved varieties, mineral fertilisers, inoculums etc. especially in the case of the resource-poor farmers. It should be noted however that these factors could not be tested in this study).

Besides the yield aspect, the scarcity of stakes is likely to limit biomass production, which influences N-fixation, and the availability of crop residues as feed. An increase in stake density and height might therefore lead to a strong increase in N-fixation and could lead to positive N-budgets even for resource-poor farmers.

Availability of organic manure is also crucial and was strongly correlated with biomass production and therefore the availability of crop residues as quality feed for livestock and N-fixation. The government program 'one farm one cow' which provides cows to the poorest farms (Type 1) might lead to higher manure availability but it is questionable if enough feed is available for these animals (Klapwijk 2011).

Available P in the soil was also strongly correlated with grain yield and biomass productivity, which suggests that P based fertilisers (through manure or in mineral form), could contribute to increased yields and BNF.

In Bugesera where drought is the main concern of farmers to intensify bean cultivation, options for intensification need to consider this. Improved drought tolerant varieties are needed here. ISAR worked on this in the last years and bred the bush variety RWR 1180 that is stated to be drought tolerant and early maturing in 75 days (ISAR 2010). This needs to be tested and if the variety is suitable for farmers it needs to be made available to farmers using an approach that takes the whole seed system into account.

In the swamps, early flooding is the main yield-reducing factor for bush beans. This calls for and an institutional approach. Such an approach could stimulate communication between the water regulating authorities and the farmers' associations to ensure that the flooding (which is regulated mechanically) is timed with the growing cycle of beans and that farmers are informed on the time of flooding to consider this for crop planning.

Farm Type Dependent Niches

This study highlights that farmers of different farm types use different farming practises with different orientations to grow beans and with varying limitations. Niches for an intensification of beans are therefore very much farm type dependent. As shown in Figure 16, the orientation of farmers to grow climbing beans varies (indicated by arrows and their size) across farm types which gives an indication about what aspects to address with legume technologies.

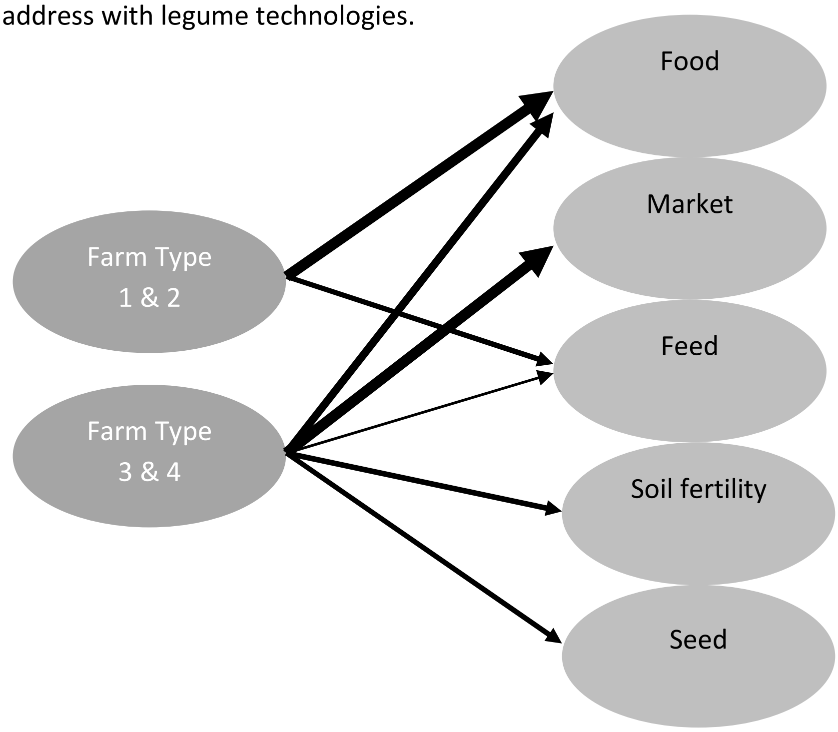


Figure 16. Orientation of farmers to grow beans across farm types

Farmers of Type 3 and 4 have a much more diverse orientation of cultivating beans than farmers of Type 1 and 2. Legume technologies for farmers of Type 1 and 2 need to address the consumption and subsistence aspect first and the low availability of resources. Most relevant are technologies to increase yields and food self-sufficiency by increasing their access to inputs (especially stakes and varieties). However, labour availability is a major constraint by those farmers (and cannot be compensated by hiring labour), and all technologies to address niches need to be labour efficient and lead to an overall reduction of labour demand.

As this study shows, improved varieties have already been promoted in the study area since decades but mostly benefit resource-rich farmers who keep seed. Improved varieties are supplied to all farmers but no long-term strategies are established to ensure that resource-poor farmers can access the seed again in case it was not kept and lost. Future programs need to consider the different seed handling practises of farmers and implement strategies, so that resource-poor farmers can access improved seed every season. Such strategies might involve resource-rich farmers who keep seed and could be provided with incentives to supply seed to other farmers (compare 4.1).

Furthermore, resource-poor farmers have different variety requirements. Since these farmers consume large amounts of immature plant parts, varieties need to be suitable for fresh consumption. According to the farmers' perception, N_2AFRICA promotes improved varieties (released by ISAR and CIAT in 2010) that are suitable for high grain yields and less suitable for consuming immature plant parts. This aspect needs further exploration to clarify if farmers in other sites have a similar perception. Farmers' quality demands in terms of taste and cooking quality need to be further studied and such criteria considered in breeding programs those disseminating seeds.

These issues call for the establishment of a seed system, which on the one hand considers the different variety requirements of farmers of different resource endowment and makes these varieties accessible to all farmers including the resource-poor. Farmers and local authorities need to be supported in order to find solutions for possible seed exchange strategies on the cell or village level and a platform where farmers with different variety demands can assess the different qualities of new varieties.

Other niches for improvements are aspects currently not in focus of farmers including soil fertility management. Farmers do not consciously focus on increasing or maintaining soil fertility, which is underlined by their crop residue management resulting in negative N-budgets. Therefore, there is a niche for interventions to improve the soil fertility management of resource-poor farmers. If such farmers could get access to additional animal feed resources e.g. through cultivating Pennisetum on all field borders (as suggested by Klapwijk 2011), this would allow them to retain bean crop residues on the fields and to produce more manure. Both would increase N inputs and could result in positive N-budgets.

Technologies addressing farmers of Type 3 and 4 have several niches to increase productivity, N-fixation and profitability. Technologies especially need to focus on marketing options by increasing the productivity on the one hand and by supporting marketing strategies e.g. group marketing to larger buyers or directly to city markets.

Farmers of Type 3 and 4 have relatively high yields through available inputs and good management. To further increase yields, legume technologies such as improved high yielding varieties are suitable for these farmers and likely to be used and kept on the long-term. Improved staking technologies with opportunities for climbing beans to climb higher e.g. through combinations of long stakes and ropes, could further boost the production and are likely to be applied by farmers of Type 4. If such technologies would require initial investments and more labour, farmers of this category could still implement it since they have enough capital and labour force available (through hiring).

Biomass increasing technologies also increase total N-fixation, which could lead to N-budgets that are more positive and increase positive rotational effects for succeeding crops.

Technologies to increase the N-fixation rate, for instance through inoculation or improved varieties with high fixation rates through an increased symbiosis, would directly lead to higher N inputs into the farming systems since most of these farmers retain bean crop residues on their fields.

5. Conclusions

This study focuses on Rwandan bush and climbing bean farming systems and explores potential niches for legume technologies. The framework of the detailed farming systems characterisations provides relevant quantitative and qualitative information for exploring farming systems. However, the detailed approach and the studying of only one season limit the scope of this study. To measure N-fixation in farmers' fields, the natural abundance method proves useful. For verification, it should be coupled to other methods.

The results provide detailed insights into the current management practises of farmers and the soil fertility status of their farms. Differences of crop residue management, availability of labour, manure and stakes across farm types are crucial to be recognised for interventions. The Ubudehe governmental household typology has proven useful to stratify farms and to provide relevant information to tailor legume technologies to farms of different resource endowment, which might lead to an increased adoption.

In Northern Rwanda, climbing beans fit into a niche due to favourable agro-ecological, social, and economical factors. Some resource-rich farmers who apply relatively good management practises (staking quality, varieties, manure etc.) and achieve relatively high yields and positive partial N-budgets, already benefit from the type of technologies currently promoted by projects such as N_2AFRICA (i.e. high yielding varieties and mineral fertilisers).Resource-poor farmers achieve lower yields than resource-rich farmers and often do not apply good management practices. Future interventions aiming to increase productivity and N-fixation of climbing bean among resource-poor farmers need to address their specific constraints. To intensify their productivity and increase benefits from N-fixation, potential technologies include the availability of a sufficient number and height of stakes, manure, and animal feed. Especially staking practices were strongly correlated with grain and biomass yield and suggesting it as an important factor influencing yield.

Especially resource-poor farmers prefer climbing bean varieties that not only give high grain yield, but also produce edible green plant parts. Some interviewed farmers indicated that this is currently insufficiently recognised by projects like N_2AFRICA distributing new climbing bean varieties among farmers. Besides, an institutional approach is needed to establish a seed system where improved varieties are accessible in the long-term to all farmers including the resource-poor (who currently often have no access to the latest varieties because they do not keep bean seed).

In Bugesera, the farming system is under constant change due to the recent settlement, an unstable climate and government interventions. Bush bean and soybean cultivation is currently reducing due to mainly environmental constraints (on hill fields). Interventions therefore need to focus on strategies to stop the reductions of bean-cultivated area and the abandoning of soybean by providing drought tolerant varieties and access to markets. The increasing role of groundnuts in the cropping system needs to be further studied including the potentials of N-fixation, the price elasticity for this crop and socio-economic factors.

This study shows that potential niches for legume technologies to make N-fixation work for smallholder farmers in Rwanda and other African countries are site and farm type dependent.

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7. Annex

Annex 1

Protocols of the Detailed Framing Systems Characterisation

Data collection sheet 1: General village characteristics

Asked to few key persons e.g. agricultural officer, farmers etc.

1.1 When did farming start in the area?

1.2 Main occupation(s) in the village (if farming, also describe the type of farming, e.g. arable, vegetable or livestock):

Have they changed over the last five years? If yes, how?

1.3 Have any development projects with legumes taken place in the village before? If yes, what kind of program?

1.4 Distance from the village centre to a main (tarred) road (km)?

1.5 Type of connection between the village and the main road (e.g. dirt road, path accessible for (motor)bikes).

1.6 Distance from the village centre to a market (where farm inputs can be purchased and produce sold) (km)

1.7 Time to travel from village to the market (also give mode of transport)

Data collection sheet 2: First characterisation of farm

Farm code: ....

Name of household head: .... Name of person interviewed: ....

2.1 Family history and composition

Since when is this family living/farming on this land?

Did they or their ancestors immigrate from other areas?

Fill in the following table on all household members:

Name	Relation to household head	Gender (M/F)	Age	Schooling level 1. primary 2. secondary 3. post-secondary 4. university 5. informal education 6. other	Main occupation	% of time devoted to farm activities (please tick)			
						0-25%	25-50%	50-75%	75-100%
1.									
2.									
3.									
4.									
5.									
6.									
7.									
8.									
9.									
10.									
11.									
12.									

2.2 Cropping history

The production of which crops is expanding or decreasing or has been abandoned on the farm?

Expanding crops Why?

Decreasing crops Why?

Abandoned crops Why?

2.3 Farmer perception of bean production

How do you judge the importance of legumes for your farm relative to other crops?

Please rank crops in order of importance:

What are the main benefits of growing legumes (e.g. rotational effects, family nutrition, fodder provision, market opportunities, etc.)?

Please rank in order of importance:

What are the main constraints to legume production (e.g. pests and diseases, land, labour, inputs, markets, etc.)?

Rank constraints in order of importance:

Would you like to expand the cultivation of legumes? How (e.g. larger area, higher yields, intercropped with non-legume crops)?

What is a good legume crop variety (crop duration, type of grain, leafiness)? How do the current varieties fulfil these requirements?

Are you familiar with the inoculation of legumes? Which legumes? Why do you inoculate?

Do you apply fertiliser (including organic inputs) to legumes? What kind of fertiliser?

Have you noticed any rotational effects of growing legumes on following crops? If yes, what kind of effects?

Data collection sheet 3: Livestock

3.1 Animals and productivity

Animal and type (local, mixed or hybrid?)	Number	Productivity (livestock products, not manure) (e.g. milk/day; eggs/week; kg of meat, etc.)	Amount of produce sold, for which price (e.g. price per egg or per litre of milk)	Amount consumed by the household

3.2 Feed origin

Feed type (if pennisetum, F=field or B=borders)	For which animal(s)	Purchased feed (yes/no, %)	Exchanged feed (against what) (yes/no, %)	Grazing on 1) fields or 2) pastures?

3.3 Manure management

Which manure is collected? How is it stored? To which crops is it applied?

Manure from which animal(s)	Amount collected (e.g. per month or year)	How stored? (e.g. on a heap protected from sun or in bags)	Applied to which crop(s)

Data Collection sheet 4: Field characterisation

Farm Code: Name of Farmer: GPS Waypoint of household:

Field No.	Crop (also indicate pasture or fallow)	GPS Waypoints (all corners, for fields < 20x20 m in addition with tape measure)	Soil type Assessed by interviewer (e.g. sandy soil)	Slope class F = Flat S = Steep V = Very steep	Visible erosion 1 = no erosion 2 = moderate erosion 3 = severe erosion	Drainage / infiltration 1 = poor 2 = good 3 = excessive	Soil samples Yes / No How many samples & any remarks	Stakes for climbing beans 1.Count no. of stakes per area (e.g. 10 m row) 2.Indicate approximate height 3.Type of material (wood, Pennisetum)
1								
2								
3								
4								
5								
6								
7								

Data collection sheet 5: Crop management

Field No.			
Crop in current season			
Variety name (called "local", "hybride" or "improved"?)			
Intercrops (estimate contribution) (use a separate column for major secondary crop(s)			
Land ownership (O=owned, R=rented)			
Rotation	2010A crop/fallow		
	2010B crop/fallow		
	2011A crop/fallow		
	2011B crop/fallow		
Seed source	P = Purchased S = Saved E = Exchanged D = Donated (e.g. by NGO)		
Manure used	Type		
	Amount (unit)		
	When applied (e.g. at planting)		
	Origin		
Mineral fertiliser 1	Type		
	Amount (unit)		
	When applied		
	Origin		
Mineral fertiliser 2	Type		
	Amount (unit)		
	When applied		
	Origin		
Biocides herbicides, fungicides, insecticides	Type		
	Amount (unit)		
	When applied		
	Origin		
Inoculant (legumes)	Type		
	Origin		
Harvest	Harvest expected by farmer (in current season, a poor season, and excellent season)	Current: Poor: Excellent:	Current: Poor: Excellent:
	Reason for variation		
	Amount sold		
	Amount consumed		
	Amount for seed		
Residues	Left in the Field (%) Incorporated, burned?		
	Collected & fed to livestock (%)		
	Grazed by animals (%)		
	Others (%)		
Farmers fertility class	(1=very fertile, 2=fertile, 3=non-fertile, 4=not fertile at all)		

5.2 Crop Activities Calendar

E.g. land preparation, sowing, manure application, fertiliser application, weeding, biocide application, harvest, processing

If two fields with legumes fill in for both if different (not because of different sizes but because of other reasons)

Management activities	Source of labour (H/F/H&F) H = hired F = Family labour	Amount of labour (= day working per month x hours per day)											
		Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec

Data collection sheet 6: Markets, income and expenditures

6.1 Sale of crop produce

Crop product and amount sold	Type of market (M=middlemen L=Local market U=Urban market)	Price at harvest (e.g. per kg) (average, min and max)	Price after storage until prices are highest (average, min and max)	When are prices highest? (months after harvest)	When was the produce sold (months after harvest)	Transaction costs of sale (transport, packaging etc.) Indicate unit!
		Average: Min: Max	Average: Min: Max			
		Average: Min: Max	Average: Min: Max			
		Average: Min: Max	Average: Min: Max			
		Average: Min: Max	Average: Min: Max			
		Average: Min: Max	Average: Min: Max			

6.2 Off-farm / non-farm income

Income generating activity	Family member(s) involved (name + relation to household head)	Amount of labour invested (e.g. …hours per day and …days per year)	Income from this activity (per month or per year)	Labour market (please tick)		
				Within village	Nearby village / town	City

6.3 Other sources of income (remittances, pension, governmental aid, etc)

Source of income	Family members receiving it (name + relation to household head)	Amount received per month / year

6.4 Expenditures on farm inputs (for crops and livestock, e.g. seed, manure, inoculant, feed, medicines,…)

Type of input purchased	For which crop / livestock	Crops at plot number(s)	Amount purchased (local units)	Price per local unit (average price + min and max)	Obtained from (please tick)		
					Middle men / village	Local market	Urban market
				Average: Min: Max:			
				Average: Min: Max:			
				Average: Min: Max			
				Average: Min: Max:			

6.5 Expenditures on hired labour

Labour hired for which activity	Amount of labour hired (e.g. no. of days)	Payment of labour (specify the amount and kind per day)	
		Cash	Kind

7.2 Biological Nitrogen Fixation

BNF sampling was carried out together with determination of aboveground biomass.

Field no.	Legume crop	Botanical names of non-legume reference crop	Number of nodules at the roots of 5 legume plants	Area harvested for aboveground biomass determination (m^2)	Total fresh matter biomass from harvested plot	Fresh matter weight of sample (g)	Dry matter weight of sample after drying (g)
				Only if BNF is assessed at a different time than final yield			
			Plant 1: Plant 2: Plant 3: Plant 4: Plant 5:				
			Plant 1: Plant 2: Plant 3: Plant 4: Plant 5:				
			Plant 1: Plant 2: Plant 3: Plant 4: Plant 5:				
			Plant 1: Plant 2: Plant 3: Plant 4: Plant 5:				

Data Collection sheet 7: Yield and BNF measurements

7.1 Grain and stover yield

Farm Code: .... Name of farmer: .... Date:…………………….

Estimate grain and stover yield of all legume crops the main non-legume annual crop(s). In case of intercropping, use a separate line for each crop.

Field no.	Crop	Total area of the field	Area harvested for yield determination (m^2)	Number of plants harvested	Grain			Stover		
					Fresh matter weight of harvested grain (g)	Fresh matter weight of grain sample (g)	Dry matter weight of grain sample after drying (g)	Fresh matter weight of harvested stover (g)	Fresh matter weight of stover sample (g)	Dry matter weight of stover sample after drying (g)

Annex 2

Amount of seed used for planting (kg/ha)

Crop	Seed planted (kg/ha)	Source
Climbing beans	30	KARI
Bush beans	30	CIAT
Maize	15	IITA
Groundnut	90	ICRISAT
Potatoes	2000	CIP

Annex 3

Input and crop/seed prices

Input	Characteristics	Unit	Price
Labour		RWF hour^{-1}	85
DAP	18-46-0	RWF kg^{-1}	490
NPK	17-17-17	RWF kg^{-1}	320
Urea	46%	RWF kg^{-1}	340
Cypermethrin	5.44%	RWF kg^{-1}	3500
Ridomil	from Syngenta	RWF kg^{-1}	14000
Mancozeb	80%	RWF l^{-1}	3500
Stakes		RWF stake season^{-1}	5
Produce	Maize	RWF ha^{-1}	140
	Potatoes	RWF ha^{-1}	150
	Groundnut	RWF ha^{-1}	1000
	Bush and climbing beans	RWF ha^{-1}	275
	Cassava	RWF ha^{-1}	100

Annex 4

Energy and protein contents of selected crops

Crop species	Energy in DM (kcal/100 g)	Protein (%)
Groundnuts	570	23
Maize	345	9.4
Cassava	467	3
Bush beans	320	22
Potatoes	400	10
Banana	328	6
Sweet potato	211	4.2

Source: FAO (1995) Food and Agriculture Organization. Agriculture, food and nutrition for Africa, Rome

Annex 5

Farmers' perception on variety characteristics of climbing beans and the organisations which disseminated these.

Variety	Introduced by whom and year	Pest /disease characteristics	Yield	Taste	Colour	Popularity	Frequency found per studied field
Ngwinurare	RADA 2005, DERN 2002-2007	Resistant to diseases	+++	++	red	Only among DERN farmers	7
Gasirida	DERN since 2010 (N2Africa)	No yet known	+++	+++	Light blue	Very new, not yet known	7
Serayi	MINAGRI 2000	Not liked because mice cut the shoots	++(+)	++	red	Very well known	3
Nyiragisenyi	MINAGRI 2000	No problems	++(+)	++	White with dark line	Very well known, more liked than Serayi	2
Nyiragateya[a]	Canadian NGO 1990	Not known	++	+++ for fresh beans, + for dry beans	red	Known but not cultivated due to small dry beans	1
RWV 2070	DERN 2010 (N2Africa)	Birds eat the flowers and young pods	++++ Big seeds	+++	kaki	Very new, not yet known	3
Kinigi	Not known		+++	+ because black after cooking	Light blue	Very well known	1
RWV 296	ISAR 2006	Resistant to disease	+++	++	White with red line	Not known	1
Local mixed							3

[a] The only variety which is suitable for eating green beans

Annex 6

Crop	Mean contribution per farm and season (%)	
	September-January (A)	March-July (B)
Bugesera		
Banana	16	17
Beans	20	7
Cassava	20	20
Coffee	4	4
Fallow	11	4
Sorghum	0	12
Maize	8	1
Groundnut	6	1
Pennisetum	5	5
Potatoes	6	3
Sweet potatoes	1	1
Vegetables	2	1
Bush	4	4
Unknown	0	20
Burera		
Climbing beans	44	35
Maize	37	7
Sorghum	0	45
Potatoes	9	0
Banana	2	2
Sweet potatoes	2	1
Vegetables	1	4
Forest	4	4
Unknown	0	3

In season C (July-December) bush beans and maize are cultivated in the swamps of Bugesera, according to the government policy on land consolidation

Annex 7

Farm	Field	Replicate	Pods		Shoots		Plant [a]		Reference plants			%Ndfa (%)	N in crop kg/ha			Ndfs kg N/ha	Est. plant available N	N_2-fixed kg N/ha		
			%N	atom% ^{15}N	%N	atom% ^{15}N	atom% ^{15}N	$\delta^{15}N$	%N	atom% ^{15}N	$\delta^{15}N$		shoots	pods	Total			shoots	pods	Total
I	1	A	3,01	0,3663	2,86	0,367	0,367	0,599	5,10	0,368	4,778	60	48	39	87	35	352	29	23	52
I	1	B	2,66	0,3662	3,26	0,366	0,366	0,054	2,80	0,368	5,326	70	64	49	113	34	352	45	35	80
II	6	A	3,26	0,3668	3,22	0,367	0,367	1,887	4,23	0,368	5,910	50	42	23	64	32	316	21	11	32
II	6	B	2,97	0,3660	3,42	0,366	0,366	-0,427	2,72	0,368	4,614	74	81	47	128	33	316	60	35	95
II	7	A	2,73	0,3661	3,68	0,368	0,368	4,031	3,25	0,368	5,146	15	80	30	110	93	363	12	5	17
II	7	B	3,72	0,3660	3,61	0,367	0,366	0,466	2,03	0,368	4,955	63	74	20	94	35	363	47	13	59
II	10	A	3,44	0,3668	3,47	0,367	0,367	2,282	4,81	0,369	7,035	52	32	13	45	22	92	16	7	23
II	10	B	3,28	0,3671	3,35	0,368	0,367	2,945	5,11	0,368	5,900	37	22	11	33	21	92	8	4	12
III	2	A	3,64	0,3666	3,32	0,367	0,367	0,918	3,83	0,368	5,651	61	135	30	165	65	128	82	18	100
III	2	B	3,37	0,3666	3,73	0,367	0,367	1,109	3,58	0,368	5,053	55	139	15	155	70	128	76	8	85
IV	10	A	3,05	0,3672	3,06	0,368	0,367	3,000	3,15	0,369	6,372	40	124	58	182	110	273	49	23	72
IV	10	B	3,15	0,3669	3,31	0,367	0,367	1,487	3,27	0,368	5,992	55	161	44	205	92	273	89	24	114
IV	9	A	3,28	0,3667	3,44	0,367	0,367	1,382	3,46	0,369	6,710	60	172	41	213	85	157	103	24	128
IV	9	B	3,59	0,3665	3,63	0,367	0,367	1,649	3,35	0,368	5,534	50	203	45	248	123	157	103	23	125
V	1	A	3,41	0,3663	3,69	0,366	0,366	-0,436	3,51	0,369	6,429	80	172	36	208	42	106	138	29	167
V	1	B	3,04	0,3668	3,72	0,367	0,367	2,388	3,02	0,369	7,458	53	82	24	107	50	106	43	13	56
V	5	A	3,91	0,3684	3,23	0,368	0,368	4,320	3,69	0,368	5,152	11	213	22	235	209	363	24	3	27
V	5	B	3,60	0,3670	4,04	0,367	0,367	2,890	5,24	0,368	4,633	26	156	20	176	131	363	40	5	45
VI	2	A	3,15	0,3672	3,25	0,367	0,367	1,300	2,61	0,368	5,348	54	285	53	338	156[b]	85	154	29	182
VI	2	B	3,38	0,3668	2,93	0,367	0,367	1,452	2,57	0,368	5,545	53	171	51	221	104[b]	85	91	27	117
VIII	4	A	3,24	0,3667	2,55	0,367	0,367	1,763	3,45	0,369	6,170	53	75	34	109	51	310	39	18	58
VIII	4	B	3,42	0,3668	3,15	0,367	0,367	1,195	3,63	0,368	4,207	47	56	33	89	47	310	26	16	42
VIII	5	A	3,60	0,3669	2,60	0,367	0,367	1,562	3,67	0,368	4,065	40	92	48	140	84	208	37	19	56
VIII	5	B	2,64	0,3665	2,55	0,367	0,367	0,718	2,70	0,368	3,939	53	65	30	95	45	208	34	16	50
VIII	1	A	4,41	0,3671	3,84	0,368	0,368	4,109	3,78	0,368	4,944	12	457	8	464	410[b]	80	54	1	55
VIII	1	B	4,06	0,3664	3,15	0,367	0,367	2,556	4,00	0,368	4,786	32	218	5	223	152[b]	80	70	2	72

(Annex 7 continued)

VIII	3	A	3,94	0,3666	3,32	0,367	0,367	0,657	3,49	0,368	4,999	61	88	18	106	42	186	54	11	64
VIII	3	B	4,40	0,3667	3,39	0,367	0,367	2,159	5,35	0,368	4,859	38	119	18	138	85	186	46	7	53
IX	2	A	2,95	0,3665	2,15	0,367	0,367	0,820	3,58	0,368	4,289	54	59	37	95	44	107	32	20	51
IX	2	B	3,03	0,3667	2,67	0,367	0,367	1,151	2,88	0,368	4,676	52	3	62	65	31	107	1	32	34
X	4	A	2,74	0,3666	2,02	0,367	0,367	1,190	3,74	0,368	3,822	44	81	92	174	97	286	36	41	76
X	4	B	2,99	0,3662	2,38	0,367	0,366	0,145	3,49	0,367	2,929	55	65	82	147	67	286	36	45	81
X	5	A	2,74	0,3668	1,96	0,367	0,367	1,408	4,33	0,368	5,206	52	42	109	152	73	309	22	56	78
X	5	B	2,39	0,3671	2,16	0,367	0,367	2,579	4,28	0,368	4,161	25	54	93	147	110	309	13	23	37
X	6	A	2,62	0,3661	2,51	0,366	0,366	-0,440	2,72	0,368	4,139	73	61	88	149	41	296	44	64	108
X	6	B	2,80	0,3664	2,48	0,367	0,366	0,504	3,94	0,368	4,409	59	101	109	210	85	296	60	65	125
XII	4	A	2,95	0,3665	2,98	0,367	0,367	1,167	2,95	0,368	5,698	58	113	86	199	84	316	65	49	115
XII	4	B	3,59	0,3665	3,48	0,367	0,367	0,984	2,94	0,368	3,726	47	70	57	127	68	316	33	27	59
XIII	1	A	3,86	0,3664	3,55	0,367	0,367	0,769	2,25	0,368	4,316	55	101	24	126	57	409	56	13	69
XIII	1	B	3,42	0,3660	3,41	0,366	0,366	0,207	2,40	0,368	4,199	63	154	30	184	68	409	97	19	115
XIV	2	A	3,20	0,3669	3,11	0,367	0,367	1,668	3,91	0,367	2,260	13	124	65	189	163	312	17	9	25
XIV	5	A	4,31	0,3667	3,22	0,367	0,367	0,883	2,80	0,368	5,184	59	44	35	79	33	329	26	20	46
XIV	5	B	3,87	0,3666	3,30	0,367	0,367	0,632	2,06	0,368	4,734	59	97	26	124	50	329	58	16	74
XIV	3	A	3,27	0,3666	2,82	0,367	0,367	1,676	3,36	0,368	5,801	52	55	25	80	38	290	29	13	41
XIV	3	B	3,38	0,3668	2,49	0,367	0,367	1,516	2,83	0,368	4,638	46	74	37	110	60	290	34	17	51

[a] based on the weighted mean; [b] Data where Ndfs exceeds estimated soil plant available N (removed for calculations)