Optimizing crop land allocation for smallholder farmers in central Uganda

Msc thesis report

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Abstract

In Uganda population growth has increased the pressure on land and most smallholder farmers are forced to farm on acreages of on average 2.5 ha. Farmers in central Uganda have difficulties acquiring more land, thus increasing farm income will likely come from making better informed choices about the allocation of land to their crops. This research will present an ex-ante analysis of the drivers of whole-farm performance, which can give preliminary insights to the farmers in exploring alternative resource allocation options. This leads to the main research question: how can the farm households in the two study districts of Luwero and Bukomansimbi improve their current resource allocation, (land, labour and capital) such that the farm households achieve food security while maximizing possible income from agricultural production? This thesis focusses on two sub-questions: (1) How food secure are the farm households? (2) What is the most profitable land allocation for each farmer, given the crops currently grown and their current yield and market price conditions? The research questions will be investigated through an analysis of farmer logbooks and linear programming where two scenarios (constrained and free) will be modelled. The constrained model will ensure a diversified food secure farm. The free scenario will only ensure a food secure farm.

From this research the lessons can be learned that using logbooks without proper feedback mechanisms and checks creates data that is not reliable. Through the continuous build-up of little errors in measurements and registration especially crop productivities are acquired that are unrealistic. To counter act this clear and regular communication with the farmers on their activities is necessary. The results show that, the optimized resource allocation solutions vary strongly per farmer. Through altering the allocation of land to various crops farmers can reduce the amount of labour necessary on the farm, increase on average their income and become more food secure. As has been indicated in the results not all farmers increase their income through the constrained and free scenarios. However for most farmers the land allocations which are simulated in the constrained and in the free scenario result in food secure and even self-sufficient farmers. The marketing of extra production improves the situation for the farmers in terms of food security. Most farmers are food secure, and those that were not can become food secure although this costs money which must come from off-farm labour. Considering price fluctuations, the diversified option would be to grow coffee, banana, beans and cassava while the economic option would be to allocate land to banana and cassava. What should be taken into account is that banana, with cassava, are the crops that can be harvested any time of the year for these farmers. This provides a constant cash flow whereas beans and coffee provide a seasonal cash boom but a more diversified income.

The results of this research must be carefully communicated to the farmers since the data on which it is based is flawed. It is here where the participatory part of the research should have come in. Due to time constraints this has not been possible but remains important for reaching the farmers and providing them with feedback on their activities and possible cropping alternatives.

Preface

In this master thesis I will try to adhere to the paradigm of natural resources management. As a master student of plant sciences with the specialisation of natural resources management I will try:

'To meet farmers' needs for welfare improvements while at the same time satisfying societal objectives for environmental protection (Izac and Sanchez, 2001).'

This will be done through a study of 26 farmers in Uganda that grow coffee and banana where I investigate their food security.

Contents

1. Introduction

In Uganda population growth has increased the pressure on land and most smallholder farmers are forced to farm on acreages of on average 2.5 ha (Bongers et al., 2015; Flores-Sánchez et al., 2014; IFAD, 2011; van Asten et al., 2012). The land pressure in Uganda increases the need to either intensify farming or find other work. (Jassogne et al., 2014, 2013; Nkonya et al., 2004; Pender et al., 2004). Moreover the productivity of the crops that most farmers grow has not increased since the early 1990's. The crop productivity is low due to low fertilizer use by the farmers and the high rates of nutrient depletion (Pender et al., 2004). High land pressure in combination with low crop productivity makes it hard for farmers to stay food secure and thus forces them to find other work (Pender et al. 2004; Nkonya et al. 2004; Dixon, Gulliver and Gibbon 2001; Kristjanson et al. 2012; IFAD 2011).

A food secure farm household can produce sufficient food for home consumption and or can additionally buy food from earnings of off-farm labour or cash crops (Carletto et al., 2013b). To sustain a farm household its consumption is defined as the amount of energy that a household needs to feed every person within that household for a whole year. In addition to the energetic value, the nutritional value of food is of importance too (Thompson et al., 1996). Nutrition, the protein, vitamin and mineral content of the products that are eaten however will not be investigated in this study. Food insecurity indicates that the household cannot provide enough food for the households consumption needs (Rufino et al., 2013). In the whole of Uganda 6% of the households are food insecure while in the area researched in this paper more than 20% of the farm households are food insecure (Shively and Hao, 2012; WFP, 2013).

A smallholder farm system in this research is a unit that comprises the household, cropping and livestock systems, that uses land, capital and labour to produce goods that can be consumed or sold (Bongers et al., 2015). The dominant crops grown in this system are coffee and banana combined in an agroforestry system. This agroforestry system is diverse and each smallholder farmer depends for considerable part on its production of coffee and banana (Oduol and Aluma, 1990). Coffee provides the household with a yearly cash boom whereas banana bunches can be eaten or sold throughout the year generating a more evenly spread income. This cropping system is dominant in the two districts where the project is active (Jassogne et al., 2014, 2013; Oduol and Aluma, 1990; Semichon-Linard, 2014; van Asten et al., 2011).

Farmers in central Uganda have difficulties acquiring more land, thus increasing farm income will most likely come from making better informed choices on the allocation of land to their crops (Carletto et al., 2013b; Etherington and Matthews, 1983; Nkonya et al., 2004; Place and Otsuka, 2002). Optimizing land allocation for maximum income can have more effect if done in a participatory fashion because most farmers have a thorough dynamic knowledge of their cropping system (van Asten et al., 2008). An economic optimisation model could, through the input of farmers be used to identify objectives for future considerations that may be attractive and feasible for the farmers (Klapwijk et al., 2014; van Ittersum et al., 2013). This research will present an ex-ante analysis of the situation which can give preliminary insights to the farmers to explore resource allocation options.

A major factor in economic performance of farms is the price of commodities. In the past few years commodity prices have fluctuated resulting in some cases to 40% increases in food prices

(Campenhout et al., 2013). Such price increases can have positive consequences for farmers if products can be sold for higher prices. Using economic optimisation the effects of increases in food prices on allocation of land, labour and capital can be analysed. This is especially helpful to farmers, if those spikes become trends (Campenhout et al., 2013). Economic optimisation models tend to favour the most profitable crops. Food prices can therefore affect the outcomes of the model. However for farmers that are not food secure these outcomes could be infeasible. Although the outcome might be infeasible for the farmer it could give insight in what would be the most economic resource allocation.

This research was part of the Sympatica project which is a collaboration between the International Institute of Tropical Agriculture (IITA) and the Hanns R. Neumann Stiftung (HRNS). The goal of the Sympatica project was to support the coffee growers in the Luwero and Bukomansimbi districts of Uganda connected to the HRNS and support in developing their farms economically. IITA is a leading research institute with a focus on research for development to find solutions for hunger, malnutrition and poverty (IITA, 2009). HRNS is a foundation that supports more than 15000 farmers throughout Uganda (Hanns R. Neumann Stiftung, 2009).

This leads to the main research question: how can the farm households in Luwero and Bukomansimbi improve their current resource allocation, (land, labour and capital) such that the farm households are food secure and at the same time achieve their maximum possible income from agricultural production? This split into two sub-questions: (1) How food secure are the farm households currently? (2) What is the most profitable land allocation for each farmer, given the currently grown crops and considering market price fluctuations?

2. Materials and Methods

2.1. Study area and farming system

Luwero and Bukomansimbi districts are located in the central region of Uganda (Figure 1), situated at 1100 to 1200 M.A.S.L. with a mean annual rainfall of 1000 to 1250 mm. There are two rainy seasons. The first rainy season is between March and May and the second rainy season between August and November (Oduol and Aluma, 1990). The soil in Luwero is relatively fertile with predominantly sandy loam soils. In Bukomansimbi the soils range from red laterite, sandy loam to loam (Gutierrez, 2013).

Figure 1. The map of Uganda. The districts in green are Luwero and Bukomansimbi (Unicef, 2010)**.**

The farms in both districts are traditional homegarden farms with coffee and banana agroforestry being practiced (Bongers et al., 2015). Homegardens are an intimate multi storied combination of many trees and shrubs around the homestead (Kumar and Nair, 2004). The farms produce food crops such as Banana (*Musa* spp.), Beans (*Phaseolus vulgaris*), Cassava (*Manihot esculenta*), Sweet potatoes (*Ipomea batatas*), Taro (*Colocasia* and *Xanthosoma* spp.), Soy bean (*Glycine max*), Potato (*Solanum tuberosum*), Maize (*Zea mays*), Pumpkins (*Cucurbita* spp.), Groundnuts (*Arachis hypogaea*), Yam (*Dioscorea* spp.), Cabbages (*Brassica oleracea*), Millet (*Eleucine coracana*), Tomatoes (*Lycospersicon esculentum*), Onions (*Allium cepa*), Eggplant (*Solanum melongena*), Cowpea (*Vigna unguiculata*), Red pepper (*Capsicum annum*), Peas (*Pisum sativum*), Pineapple (*Ananas comosus*) and Doodo (*Amaranthus candatus*). In addition to these food crops the farmers grow cash crops such as Robusta coffee (*Coffea canephora*) because of the low altitude, Avocadoes (*Persea americana*), Jack fruit (*Artocarpus heterophyllus*), Citrus spp., Guava (*Psidium guajava*), Paw Paw (*Carica papaya*), Watermelon (*Citrullus lanatus*), Vanilla (*Vanilla planifolia*) and Banana (Oduol and Aluma, 1990).

However the farmers do not grow the crops in equal quantities and or with equal priority. Most of the farmers grow five dominant crops and then a category of crops that are not grown so much. The five major crops grown in both regions are Robusta coffee as a cash crop, with banana, maize, beans and cassava as food crops. Since many crops, like sweet potato, tomato, cabbage and avocadoes are grown in smaller proportions by farmers they are lumped together in an "*other*" category. Thus six crops are considered in this research, Robusta coffee, banana, maize, beans, cassava and *other*.

In the central region the yields of coffee and banana are on average 400 – 1250 kg green bean/ha and 9000 - 15000 kg/ha fresh weight respectively (Bongers et al., 2015; van Asten et al., 2012, 2011). The farm usually includes 2.4 tropical livestock units which consists of chickens, cattle and pigs. The livestock can be found in zero grazing pens, however most farmers let their livestock graze losing the possibility of collecting manure. Even though most farmers depend on existing soil fertility and on natural climate conditions some farmers mulch and use fertilizer (Bongers et al., 2015; van Asten et al., 2012; Wang, 2014). The farms in Uganda consist on average of ten household members with an average farm size of around 2.5 hectare. Of the ten household members usually three work full time on the farm. On average 55% of total farm revenue is based on the income from coffee, 12% from banana, 14% from off-farm labour and 4% from livestock. The farm income is on average around 2300 USD a year (Bongers et al., 2015).

Since land pressure is considerable, the land that farmers in this research had during the initial survey in 2014 did not increase. Thus the total amount of land that the farmers have is fixed. However the amount of land allocated to the various crops can change. Land of farmers is split in two where one part of the land is owned and another part is rented from big land owners, the Buganda kings (Mafeje, 1973). On land that is rented annuals are often grown whereas on owned land perennials are grown. For farmers there is a possibility to buy rented land. It is however not profitable to change all land to perennials. Perennial crops require time to reach the size that ensures a constant production. Coffee is a crop managed by the men, whereas beans are managed by the women. Therefore most farmers have diverse farms, due to not owning all the lands that they have under cultivation and because crop management is split between gender groups.

Most products that are harvested by the farmers are sold in the harvested form. Only coffee and beans undergo a treatment before selling. Coffee berries are put to dry on tarps in the courtyard. The drying process will reduce their volume and will thus increase the weight per volume. Beans are often harvested with the whole plant. At home the beans will then be taken from the pods and are then either eaten or sold. The crop remains often end up on the compost heap.

2.2. Data collection

2.2.1. Previous data collection in the Sympatica project

The Sympatica project was co-financed by the Hanns Neumann Stiftung which benefits from good coffee harvests. They are a fund that trains farmers throughout Uganda in cultivating coffee such that they have a constant producer base. During previous research within the Sympatica project a household inventory with 48 farmers was made. In Luwero and Bukomansimbi districts four different villages per district were chosen from which six farmers each were selected. The farmers in Bukomansimbi were randomly chosen such that 24 farmers were prepared to participate. In Luwero active and interested farmers that could read and write were selected. Each group of six from a village had a facilitator which was the main contact for the farmers and for the project (Semichon-Linard, 2014). The household inventory considered household composition, cultivated crops and tree species diversity. In addition the farmers were asked to fill in a logbook during a full year.

Twenty-six farmers out of the 48 were selected as they consistently registered data in their logbook. The data in the logbooks entered in excel and was categorised in four sheets, an activity table, harvest table, investments and expenditure table and an income table. In the activity table time spent on daily labour activities on the farm was registered (Table 1). The household labour groups refer to males, females and children of the household and male and female hired labour, five groups in total. The time that children spend on labour helping their parents is halved to account for their reduced productivity. For the daily activities the labour group that spend time on the activity was included. Based on the data from the logbooks labour time was expressed as the total amount of labour days spent on different crops in one year on the farm. A labour day is defined as seven hour day of labour. It is possible that more hours were spent working on a day which then implies that additional people are hired. The labour that a household can supply was not only used for farm labour but also on off-farm labour. The amount of labour that a household can thus allocate for farm work is limited. The labour time per crop per area was known thus labour input per crop was calculated. In the harvest table the amounts harvested by the farmers per crop was recorded, in local units (Table 2). If the farmer sold the product then the amount sold and the price of the transaction was also recorded. This income was then added to the income table.

Table 1. The activities and categories in the logbooks.

Activity Name	Investment / Expenditure type	Income Source
Planting	Farm inputs	Remittances
Weeding	Tools	Gifts
Slashing	Building	Business
Pruning	Transport	Salary
Desuckering	Food	Casual wages
Spraying	House-items	Village savings (loans)
Thinning	Assets	Bank loans
Fertilising	Animal Health	Farm Produce
Mulching	People Health	Animal sales
Fodder collection	School fees	Others
Feeding animals	Airtime	
Tethering animals	Debts, savings and loans	
Spraying animals	Gifts/Offerings	
Shelter construction	Labour	
Cleaning animal house	Business investment	
Fencing	Other	
Digging		
Digging holes		
Digging water trenches		
Gap filling for bananas		
Harvesting		
Milking		
Processing		
Drying		
Burning		
Cutting trees		
Uprooting old plants		
Potting		
Ferrying		
Pollinating		
Irrigating		
Guarding maize		
Off farm activity		

Recorded in the investments and expenditure table are the expenses, which were categorised in different types (Table 1). Farm inputs are among others, fertilizer, herbicide, pesticides, mulch and seeds. The category has been split in two; household expenses and investments. Household expenses include tuition fees, bought food and household compliances from shoes to matches. The investments were the tools that the farmer used for a longer time than a year or seedlings that take several years to yield. In the last sheet, the income table, money earned by the household through the selling of crops and other income sources were recorded (Table 1). The data in the logbooks were recorded from 31-07-2013 till 31-08-2014. An example of a logbook is presented in Appendix A.

2.2.2. Farmer meetings

Additional data for this study was collected at organized farmer meetings. The farmer meetings were with the farmer groups set up by the facilitator and all the farmers from the group were invited. The farmers that were excluded from the research due to inconsistent data registration were allowed to participate in the meetings. Farmers that were present and had complete and consistent logbooks are included in the research.

During previous research the total amount of land of each farm was measured with a GPS. There were efforts to register even the amount of land per crop. These numbers were however not consistent, different crops and less land than in the initial survey were registered. What was clear was that these farmers intercropped all their crops and that therefore measuring a plot with one crop would not work. For this study the area of land allocated to each crop was needed. Therefore since the total amount of land was known the proportions of crops on the farmers land would give insight in land covered with each crop. During the farmer meetings the farmers were asked to indicate with 20 beans what the land proportions were for each crop. During the meeting the farmers could discuss with each other, but they had to indicate individually the share of the crops on their farm.

2.3. Data analysis

Based on what was collected during the inventory and entered by the farmers in their logbooks a table was made that comprised all data for this research. Farm income was calculated as the cumulative income in a year earned by the farmers from the price received for their crop products from traders minus farm costs from hired labour, input costs and investments. Off-farm income considers all not farm related cumulative earnings that the household made in a year. Input costs are the cumulative expenditures of the farm on inputs for one year. This is equally so for the labour costs based on what the household paid to the hired farm labourers. Investments are the cumulative expenditures of the farm on investments.

The area that is allocated to each crop by the farmers is calculated from the values acquired through the farmer meetings multiplied by the farm size minus 0.02 ha for the house the farmer has. This is based on own estimates of the areas occupied by the house with court yards. For labour the five initial groups were reduced to three, male, female and children were taken together to constitute a family labour group. The time that family, hired male and hired female labourers spend on their various activities was summed. The time the children spend on labour is halved to convert their productivity to adult productivity. Additionally the total time spend per crop was calculated without the distinction between the labour groups.

Yields were defined as the total amount of harvested product in kg. Yields of coffee, banana, maize, beans, cassava and others were estimated from the harvests that the farmers recorded in their logbooks. The harvested weights were in fresh weight and local units, which were translated to kg fresh weight. Table 2 shows all the conversion factors. Most unit weights were averaged from measurements at several farm groups by researchers from the Sympatica project (Mbabazi and Bongers, n.d.). The weight of the banana bunch has been measured by Wairegi et al. (2009). Crop productivity in this paper is the yield of the harvested product divided by its allocated amount of land in ha. Most farmers sell some of their produce; the profitability of crops was expressed as the amount of money earned by selling the products.

Table 2. Weight units for different crops, from measurements and literature (Mbabazi and Bongers; banana bunch weight: Wairegi et al. 2009).

Units	Weights per unit of crop product (kg)					
	Coffee	Banana	Maize	Beans	Cassava	*Others*
Basin	15.8		18.0	17.7	20.0	11.8
Bag	100.0		80.0	85.0	10.0	33.3
Tin	15.3			17.8	17.5	17.5
Bucket	12.0		12.0	12.0	15.0	11.8
Basket	13.3		6.0	15.0	9.0	
Cup	0.4		0.5	0.7		0.5
Katasa			6.2	5.1	4.9	
Plant*			0.5		6.5	2.9
Cob			0.3			
Bundle**				19.4	5.0	1.0
Bunch		17.0				
Tuber					1.2	0.3
Jerry can	5.0					
Box						20.0
Fruit***						0.9

*Plant indicates the products from one whole plant
**Bundle is packet of products; for beans this includes plant material.
***Fruit considers average weight of the fruits of avocado, paw paw, mango, jackfruit, water melon, pine apple, passion fruits and eggplants.

Data from the logbooks were calculated in excel from which the household, labour and yield data were accessed by R. R is a free-ware statistical program. Figure 2 shows the process from logbook to scripts. The four data sheets on the left represent the activity, expenditures, harvest and income tables. These tables constitute a logbook of one farmer. Thus from 26 farmers logbooks have been summarized to yearly figures which have been condensed to one excel file. The summarizing table is combined with another excel file containing the area data of the farmers in R. The yield and land allocation data from the farmers meetings were combined in R. This data was used to calculate additional parameters, such as labour input and crop productivity, for the economic optimisation model. The calculations have been done in various scripts such that the scripts of the optimisation model could base its values on those calculations. Specific scripts were made for the division of land for each farmer based on the farmer meetings, crop productivities and for the food self-sufficiency and food security, all attached in the appendix.

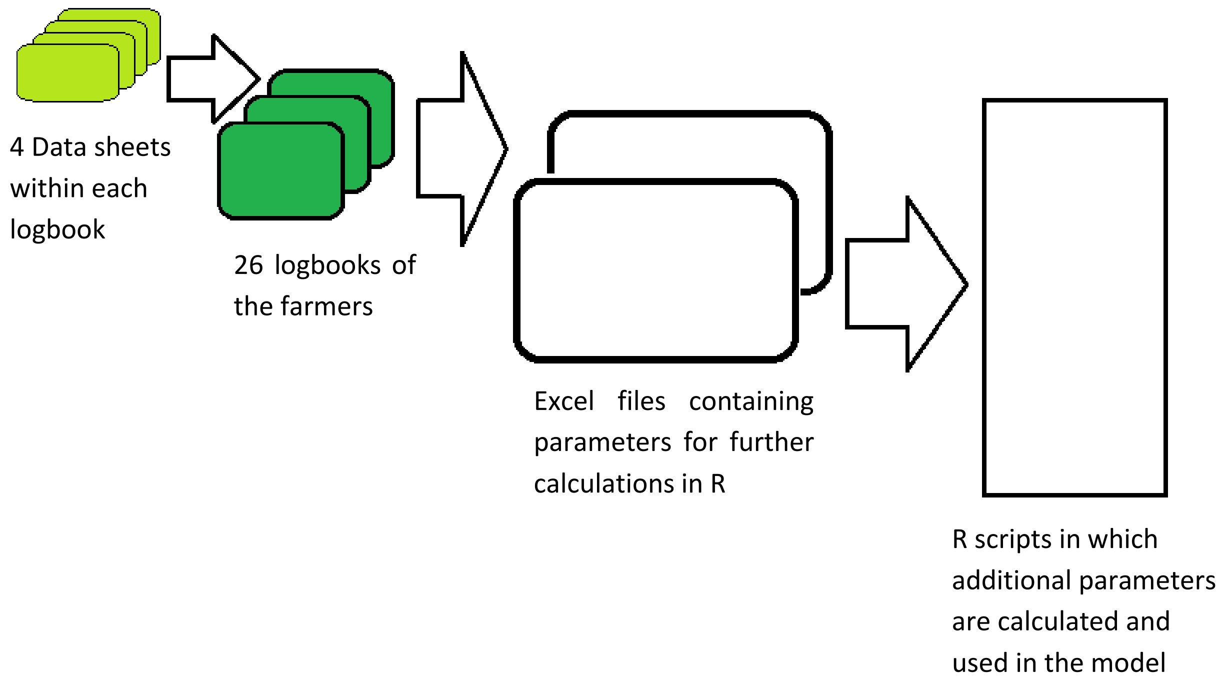

Figure 2. Flow diagram of farm data for the calculation of parameters.

2.3.1. Food self-sufficiency and food security

The food self-sufficiency (FSS) index considers the amount of energy produced compared to the household needs. The food security (FS) index considers the amount of energy produced plus the amount bought by the household compared to the household needs (Rufino et al., 2013). The amount of energy that a household needed was calculated with the household size and age groups. Because the data that has been collected regards family members less than 18 years as children, their energy requirement will be based on the following calculation. Children's energy requirement was based on the average energy needs from birth till 18 years. Based on this two average daily kilo caloric values are estimated based on Brody (Brody, 1999a): children younger than 18 years of age need 7500 kJ d^{-1} and adults 10 000 kJ d^{-1}.

$$FSS = \frac{energy\ produced}{energy\ \ required\ for\ the\ household}$$

$$FS = \frac{energy\ produced\ +\ energy\ bought}{energy\ required\ for\ the\ household}$$

The energy produced, expressed in kJ, is calculated by the yield of each food crop multiplied by the caloric value summed for all food crops. Energy bought refers to additional energy necessary to feed the household paid from the household income (Rufino et al., 2013). The food that is bought is a weighted average price per energy based on a food basket. A food basket is a concept which takes various foods that are bought by a household together and estimates an average price (Carletto et al., 2013b; Chibuye, 2014; Kurre, 2003). Here the food basket approach was used to calculate a weighted average price for energy such that energy required for the household could be calculated. The food basket contains banana, maize, beans and a category others. The ratio of the food in the bought food basket is based on discussions at IITA on what kind of food farmers would buy for their consumption. On the farm the farmers consume also what they produce which is in different amounts from what they buy. Therefore a consumption ratio is used per crop, which can be seen in Table 3. The consumption ratio defines how much of the diet of the household is based on each food product. The bought ratio is used when the household is not able to supply all the food from the farm and food needs to be bought. Farmers are not inclined to buy cassava hence the zero. The consumable parts parameter is used for the calculations on the weight of products that are destined to be consumed by the household. It applies to the bought products because the household will only buy products for consumption.

Table 3. The content of the bought and consumption food basket and parameters related to nutrition and price.

Food products	Bought ratio (-)	Consumption ratio (-)	Energetic value of edible content[6] (kJ (100 g)$^{-1}$)	Consumable parts (-)	Whole sale price (UGX kg^{-1})	Retail price[4,5,8] (UGX kg^{-1})
Coffee	0	0	0	0.45[9]	0	2350
Banana	0.3	0.5	510	0.60[1]	390	1000
Maize	0.4	0.1	720	0.66[7]	510	950
Beans	0.2	0.25	1255	0.4[3]	1800	1950
Cassava	0	0.05	670	0.83[2]	480	520
Others	0.1	0.1	420	0.8	1000	1000

1. Hauser and Asten 2010;
2. Naziri et al. 2014;
3. Guler and Ozcelik 2007;
4. Farmgain Africa Limited 2014;
5. FIT Uganda ltd and Agricultrual Sector Program Support;
6. Hotz et al. 2012;
7. Ali 2003;
8. Uganda Coffee Development Authority 2014;
9. Dancer 1963

For the food security calculations the weight of the food products that need to be produced or bought has to be calculated. The food products are often not completely edible hence the consumable parts factor from Table 3 is used. The weight in kg of each product to sustain the household can thus be calculated through the proportion of consumption. The units of the formula are in Table 4.

$$Weight\ of\ product\ i\ required = \frac{\left(\frac{(Consumption\ ratio\ product\ i * hh\ energy\ req)}{Energetic\ value\ of\ edible\ content\ product\ i}\right)}{Consumable\ part\ of\ product\ i}$$

Table 4. Parameters of the formula on the weight of product necessary to sustain the household.

Parameter	Unit
Weight of product	kg
Consumption ratio	-
Hh energy req	kcal
Energetic value of edible content	kJ kg^{-1}
Consumable part	-

2.3.2. Linear programming

The economic optimisation of the farm is done with data acquired from the farmers on three resources: land, labour and capital. Linear programming (LP) can aid in the analysis of allocation of resources for production goals of farmers (Betters, 1988; Heyer, 1971; Roetter et al., 2007). Linear programming was used for the economic optimisation of the land allocation for the crops of the farmers. Moreover LP can show the trade-offs within farms such that an analysis can support discussion about farming practices (Dogliotti et al., 2014b; Klapwijk et al., 2014).

The model focusses only on the farming component of the household. Therefore the household expenses and off- farm income are excluded from the model since both do not affect the model directly. This does not suggest that it cannot be used as a compensatory measure by the farmers for possible unprofitable results.

The model

For linear programming an objective function, constraints, activities and well specified boundaries are necessary (Betters, 1988; van Ittersum et al., 2014). In R an LP model was built to allow the identification of possible land allocation options for the farmers.

The objective function was to maximize the farm income based on the selling of the crop products minus the input costs, labour costs and the costs of buying food. The function focused on the different crops indicated with the *i*, i.e. coffee, banana, maize, beans, cassava and others. The weights of sold and bought amounts are in kg and prices are in Ugandan shillings, see Table 5 and Table 6 for further specifications.

$$\text{Maximize: } Farm\ income = \sum_{i=1}^{6}(amount\ sold_i * consumable\ parts * WS\ price_i) - \sum_{i=2}^{6}(\ amount\ bought_i * RT\ price_i\,) - \sum_{i=1}^{6} land_i * \ input\ costs_i - (\ hired\ labour\ * \ \ labour\ costs\,)$$

Table 5. Specification of the activities in the LP model.

Activity name	Explanation	Unit
i_1	Coffee	-
i_2	Banana	-
i_3	Maize	-
i_4	Beans	-
i_5	Cassava	-
i_6	Other	-
$Land_i$	Land allocated to crop *i*	ha
$Amount\ sold_i$	Amount sold of crop *i*	kg fresh weight
$Amount\ bought_i$	Amount bought of crop *i*	kg fresh weight
Hired labour	Amount of labour days filled by hired labour	day^{-1}
Labour costs	Labour costs for hired labour per day	UGX per day^{-1}

Since the prices from the traders for the various products for each farmer were not directly known whole sale market prices (WS in UGX kg^{-1}) or farm gate prices from September 2014 were used to calculate the earnings from each crop. Costs for buying food is based on retail market prices (RT in UGX kg^{-1}) from September 2014 (Farmgain Africa Limited, 2014; FIT Uganda ltd and Agricultrual Sector Program Support, n.d.; UCDA, 2014).

The input costs are defined as the costs of inputs per crop per hectare and they are summed to farm level. Labour input is defined as the amount of labour that the farmer uses to produce the outputs it got as labour days per hectare. The summed labour days are the amount of required labour days that the farmer needs to produce. As the farmer has two pools of labour sources to choose, hired and family, that have to fill all the labour days. Irrespective of the crop the labour that the family cannot do is done by hired labour with certain labour costs. Labour costs are defined as the costs of hired labour per day. The labour costs are based on the costs that the farmer registered for activities done by hired labour. Family labour is thus free of charge but is limited.

Table 6. Specification of parameters with their units

Parameters	Units
Bought product *i*	kg
Crop productivity	kg ha^{-1}
Current annual crop land	%
Current perennial crop land	%
Farm income	UGX
Input costs of input z	UGX ha^{-1}
Labour costs	UGX day^{-1}
Labour input *i*	days ha^{-1}
Land *i*	ha
Minimum current beans area	%
Minimum current coffee area	%
Required amount of food *i*	kg
Required labour days	days
Retail price of product *i*	UGX kg fresh $weight^{-1}$
Sold product *i*	kg
Total farm land	ha
Whole sale price of product *i*	UGX kg fresh $weight^{-1}$

The major constraints are based on land and labour and are set to the current values of each farm.

$$\sum_{i=1}^{6} land_i \leq total\ farm\ land \qquad [ha]$$

$$\sum_{i=1}^{6} (labour\ input_i * land_i) = required\ labour\ days \qquad [days]$$

$$required\ labour\ days - family\ labour - hired\ labour = 0$$

$$required\ labour\ days \leq total\ number\ of\ labour\ days \qquad [days]$$

$$family\ labour \leq available\ family\ labour \qquad [days]$$

$$hired\ labour * labour\ costs \geq 0 \qquad [UGX]$$

The allocation of crops can have major effects on food security. Therefore to ensure that the farmers are food secure a constraint per food crop was formulated based on the consumption basket. The consumption basket is the same as the food basket however each product has a consumption ratio. The consumption ratio is shown in Table 3 and based on assumptions in consultation with IITA experts.

$$(crop\ productivity_i * land_i) - amount\ sold_i + amount\ bought_i \geq weight\ of\ product\ i\ required_i, \quad i = 2 - 6 \quad [kg]$$

Farm level yields are calculated from the productivity of the crops in kg per ha. The household energy requirement for each crop is expressed in kg. This constraint ensures that for each crop the required amount of energy is available to the household.

Although the area of the farm was fixed the allocation of that land to the various crops was not, although it was not fully flexible. Perennial crop land could expand 10% of the land that was currently cropped with perennials. A similar constraint was made for the annual crops. An expansion factor of 10% was based on the estimated possibility of changing rented land to owned land. Additionally the time for the land to become productive with perennials was taken in to account. The farmers indicated during the farmer meetings that they would not reduce coffee in acreage in possible future land allocations. Thus a constraint was made that ensures that the farmers allocate at least a minimum of land to coffee. A similar thing was indicated for beans since the women of the farms cultivate the beans for home consumption and possible additional income.

$$\sum_{i=1}^{2} land_i \leq (\ current\ perennial\ crop\ land + 10\%) *\ total\ farm\ land \quad [ha]$$

$$\sum_{i=3}^{6} land_i \leq (\ current\ annual\ crop\ land + 10\%\ ) *\ total\ farm\ land \quad [ha]$$

$$land_i \geq minimum\ current\ land_i\ * total\ farm\ land, \quad i = 1, 4 \quad [ha]$$

Table 7. Specification of the right hand side, the type of constraint and units

Right hand side value	Sign	Unit
Total farm land	≤	ha
Total number of labour days	≤	days
Food security banana	≥	kg
Food security maize	≥	kg
Food security beans	≥	kg
Food security cassava	≥	kg
Food security other	≥	kg
Perennial land	≤	ha
Annual land	≤	ha
Coffee land	≥	ha
Beans land	≥	ha

To assess the robustness of the model a sensitivity analysis was done on several parameters. The sensitivity of parameters is assessed through changing one parameter at a time, each with a factor of

-10%, -5%, -1%, +1%, +5% and +10%. The parameters that were analysed for the sensitivity analysis are the total area of land, the maximum amount of labour days, labour productivity, crop productivity and the wholesale and retail prices. The land and labour right hand side values are chosen to investigate their effect as a constraint (Table 7 and details in the appendix Table 20). Productivity values are investigated because they affect the amount of land that is necessary to produce the amounts for food security or sale. The prices affect the demand and supply for the farmers and as such the profitability of the product.

The scenarios

Three scenarios were modelled to explore land allocation options: the base, the constrained and the free scenarios. The constraints that apply to each scenario are shown in Table 8.

The first scenario the base scenario is to benchmark what the model gives as an income with the current situation. It is unknown if the farms are currently food secure. Therefore the constraint on food security is excluded. The base scenario is run with farm specific crop allocations, labour constraints and crop productivities based on the farmer meetings where the current land allocation was investigated.

In the constrained scenario food security is introduced in the model. The land allocation constraints are changed from individual crops to constraints on perennial and annual crops, with minimum areas for coffee and beans only. Data is based on the farmers meeting. To assess the robustness of the model and because many parameters are used in this model a sensitivity analysis will be done on this scenario. This scenario will be closest to what farmers are be able and willing to achieve on their farm in the short run.

In the free scenario the farm has to be food secure but has no land allocation and total labour constraints. Only the maximum area of land and the current amount of family labour are constraints in this scenario. The free scenario is run to analyse the economic optimization of the farm.

Table 8. The table shows which constraints apply for each scenario. Plusses indicate the presence of the constraint in that specific scenario minuses indicate the absence of the constraint.

	Scenarios		
Constrains	Base	Constrained	Free
Food secure	-	+	+
Farm specific crop allocation	+	-	-
Perennial crops	-	+	-
Annual crops	-	+	-
Minimal coffee	-	+	-
Minimal beans	-	+	-
Total labour input	+	+	-
Family labour	+	+	+
Total area	+	+	+

3. Logbook results

This chapter will focus on the outcomes from the analysis of the logbooks. The data from the logbooks, in combination with the data from the farmer meetings, presents the household composition, the current land allocation data, the labour allocation and lastly the yield, crop productivity and labour input. This chapter will conclude with a short discussion on the results such that model outcomes in the next chapter can be clearly understood.

3.1. Household composition

The composition of the farm households that registered their data in the logbooks and were present during the farmer meetings is shown in Table 9. To complement the household composition revenues and farm expenses were added.

Table 9. Household composition, income, farm income ratio and farm expenses. The income and expenses are in Ugandan shillings. (L) stand for Luwero and (B) for Bukomansimbi

Household composition					Income and expenses (UGX)					
Household number	Gender household head	Region	HH size	HH members >18 yr	Farm revenue	Off-farm revenue	Input costs	Labour costs	Investments	Percentage of revenue from farm (%)
1	Male	L	6	3	2,973,700	3,621,800	690,540	178,003	81,000	45
2	Female	L	8	1	3,228,000	40,000	426,927	100,000	32,000	99
3	Female	L	4	2	1,393,600	390,000	370,297	302,500	7,000	78
5	Female	L	9	4	1,496,200	927,000	216,004	141,504	7,500	62
7	Male	L	9	3	7,202,700	13,873,200	2,604,798	609,000	229,500	34
8	Male	L	6	2	465,950	921,900	1,347,494	108,994	36,400	34
10	Male	L	10	3	2,344,150	1,313,500	1,477,432	7	20,500	64
11	Male	L	9	7	3,401,800	1,014,000	850,815	0	0	77
12	Male	L	6	3	562,000	1,932,000	1,009,989	3,500	2,000	23
14	Female	L	7	3	592,500	2,808,000	572,760	947,500	0	17
15	Female	L	5	3	363,000	1,762,000	397,274	4	0	17
16	Male	L	8	2	1,002,200	18,478,000	1,296,174	494,594	134,700	5
21	Male	L	17	7	1,086,100	1,755,700	1,216,951	4,500	96,500	38
24	Male	L	6	2	3,836,700	4,149,000	1,127,056	659,502	56,000	48
31	Male	B	3	2	3,142,100	1,581,500	2,172,707	829,500	12,500	67
33	Male	B	2	2	36,000	134,000	316,476	60,000	17,500	21
37	Male	B	6	2	2,643,200	2,691,900	661,980	194,499	58,200	50
39	Male	B	7	2	2,587,150	1,706,300	507,302	72,000	10,500	60
40	Male	B	5	2	1,753,200	2,291,300	428,912	270,000	30,000	43
41	Female	B	9	4	984,300	12,578,200	625,821	687,200	64,500	7
43	Female	B	6	4	758,200	2,782,500	915,673	62,900	169,600	21
45	Male	B	8	2	445,500	2,451,400	977,111	121,004	100,700	15
48	Male	B	5	2	2,631,150	450,000	802,343	47,000	71,700	85
49	Female	B	3	1	85,800	481,500	284,230	12,000	1,000	15
51	Male	B	12	4	1,804,900	303,700	514,774	1,878,900	31,600	86
52	Male	B	2	2	4,769,550	804,600	542,996	1,042,300	44,500	86

The household expenses are kept out of this table since they affect the household but not the farm. The farm expenses are split in the farm input costs, labour costs and the investments. Eight of the 26 farms are headed by a female which is more than 30% of all the farms. Fourteen farmers are from Luwero and twelve farmers are from Bukomansimbi. Most farmers buy inputs for their farms but not necessarily hire labour or invest in their farm. In the last column the percentage of the household revenues from the farm is shown. When the percentage is above 75% then the main source of the revenue of the household is from the farm, which is the case for six farmers. For nine farmers the opposite is the case where the income of the farm is below 25% of the household revenue. Eleven farmers are in between the 25% and 75% indicating that farming is not necessarily their sole occupation.

3.2. Land allocation

Figure 3 shows that most farms have a size that is below 1 hectare and both graphs show that the farms are not normally distributed. In Figure 3B the zero shows the median value. The farm areas are not on a 1:1 line which will affect further calculations based on farm size. The Q-Q plot shows next to that the group of farmers is not normally distributed that the amount of land that the farmers have is skewed, to many small farms and a few relatively big ones.

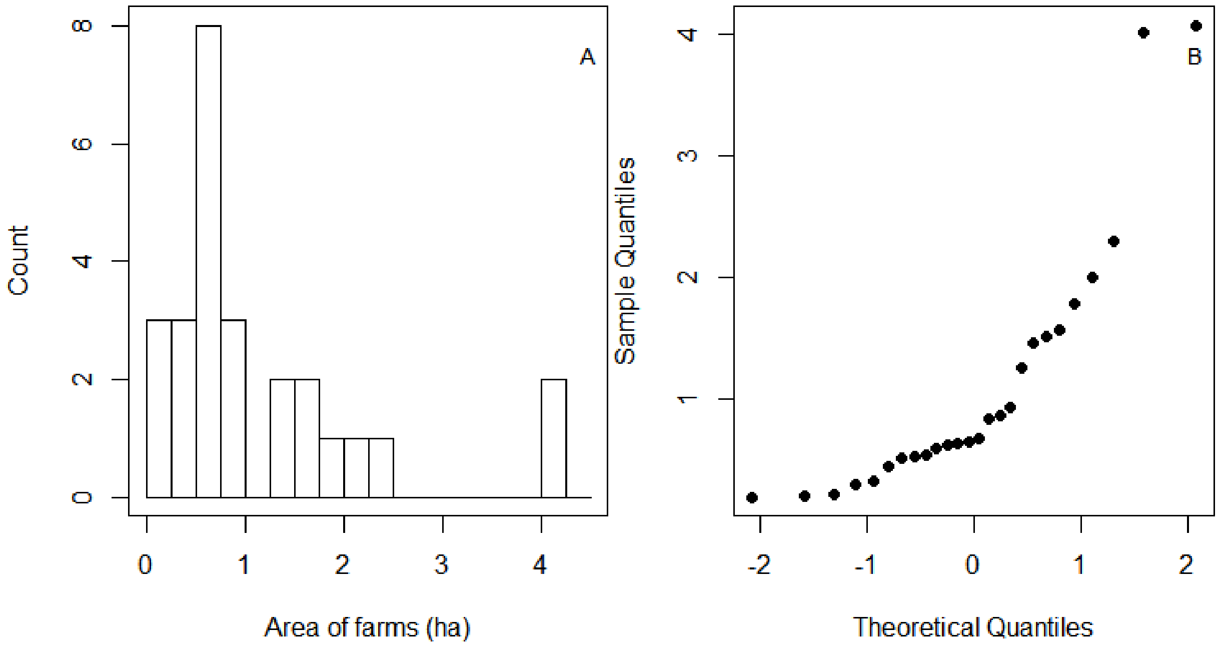

Figure 3. (A) Histogram showing the counts of the farm acreages in ha. (B) Q-Q plot of the total farm size. The zero of the x-axis is on the median.

Two farms (3 and 10) had more than 4 ha which in their case was more than two times the size of the other farms. These farms distorted the calculations on average farm size (average = 1.12 ha, median = 0.66 ha). Figure 4 shows there was no relation between farm size and farm income. Hence, a larger farm size does not imply a higher farm income. Some farms have a negative income which means that their farm expenses are bigger than the farm revenues of their farm products.

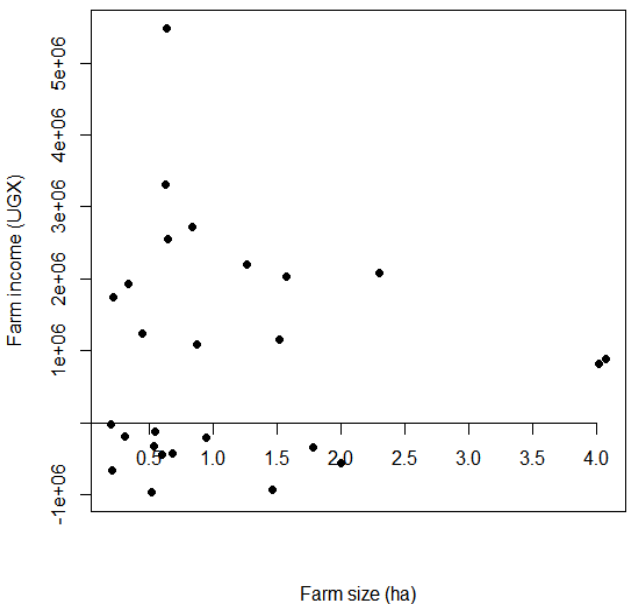

Figure 4. Income (UGX) plotted against farm size (ha).

When the farms are sorted according to their size the relative allocation of land to crops, showed no differences between crop allocation and land size (Figure 5). All crops are grown by all farmers. Notice that farmers seem to choose between the cultivation of maize or banana. The graph shows the area of the crops as being grown on distinct plots. All farmers were intercropping so it's more the coverage of the crops on the land in percentages that should be noticed. The data presented is further detailed in the appendix (Table 16).

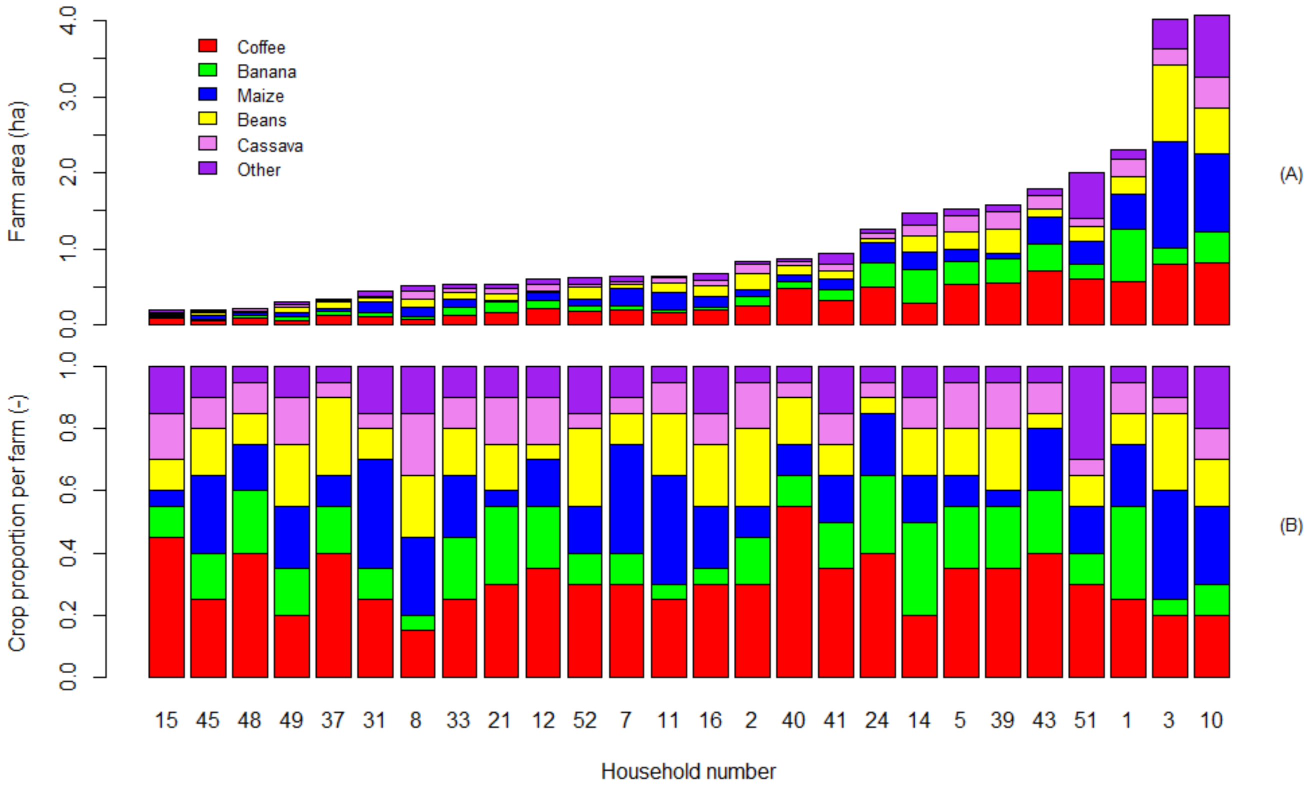

Figure 5. Sorted land size with the amount of land allocated to each crop. (A) The farms are ordered based on their farm seize in hectares. (B) Shows the allocation of each crop in percentages by the farmer in the same order as for (A).

3.3. Labour allocation

The time spend on working on the farm is shown in Figure 6 and the values on which this graph is based are in the appendix (Table 17). The total amount of labour on the farm is shown, differentiated per crop in Figure 6A. The male headed households spend on average 100 labour days more (Table 10). If the median is considered the difference is almost 200 labour days. There is one female headed household that spends much more time on her farm than any other (farmer 43). The graph is ordered by farm size as in Figure 5.

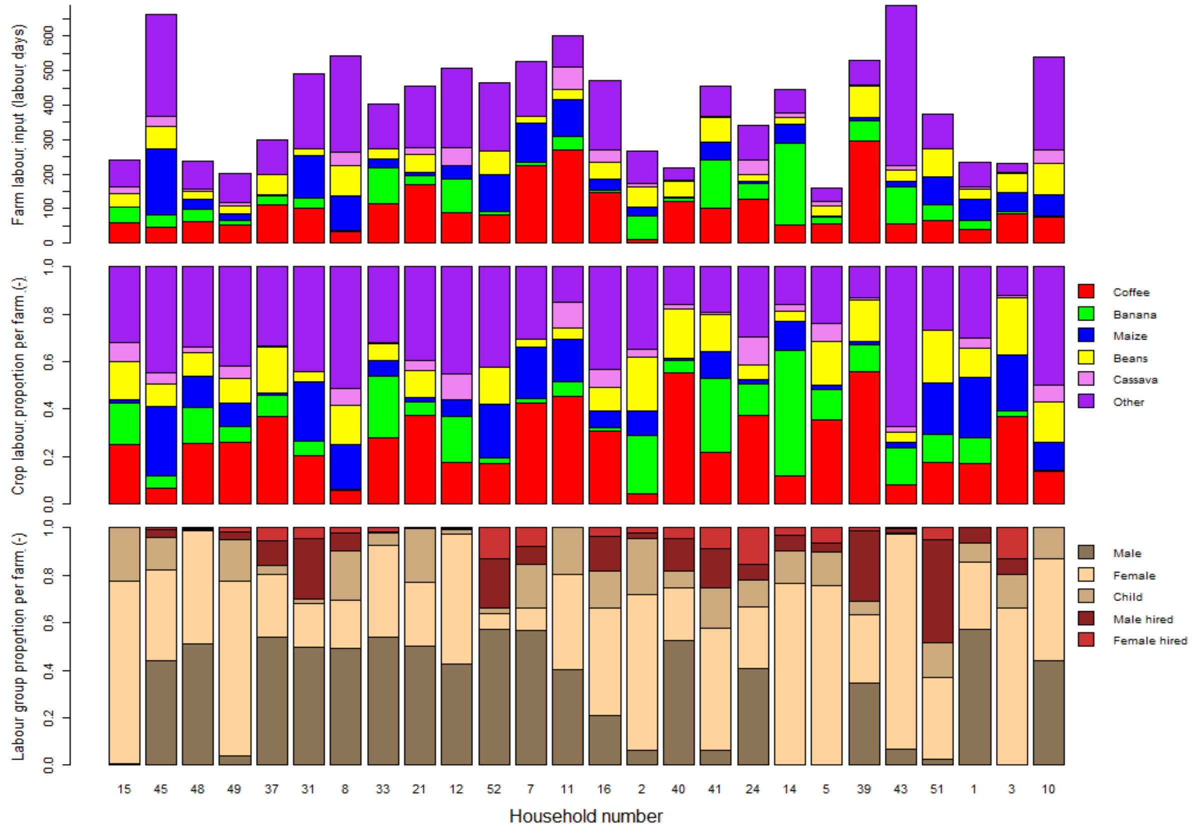

Figure 6. Labour input per farm differentiated per crop. The household numbers are sorted on farm size which increases from left to right.

Table 10. Labour input divided per household head. In labour days over one year of registration

Head of household	Min.	1st Qu.	Median	Average	3rd Qu.	Max
Female	160	220	250	340	450	690
Male	220	350	470	440	530	660

Figure 6B shows the proportional labour input per crop. What can be noticed is that for Figure 6A and B the category "other crops" takes up much of the labour input. The crops that are considered in "other" are rather diverse and consists mostly of vegetables and fruits, crops that need attention and are vulnerable. In Figure 6C all the different labour categories are shown. On average, the farms do not use much hired labour compared to the labour that the family puts in the farm, with a few exceptions (farmers 29, 31, 51 and 52). Over the year the median labour input per month does not differ very much (Figure 7), but the variation is quite large. September shows the highest labour use because of the coffee harvest and February has the lowest labour input, it is the month before the next harvest and planting season. Notice the huge variation for April and August. April is for some the harvest and weeding month mostly of the annual crops. In august another harvest is done but focussed on the coffee and some planting is done for the next season.

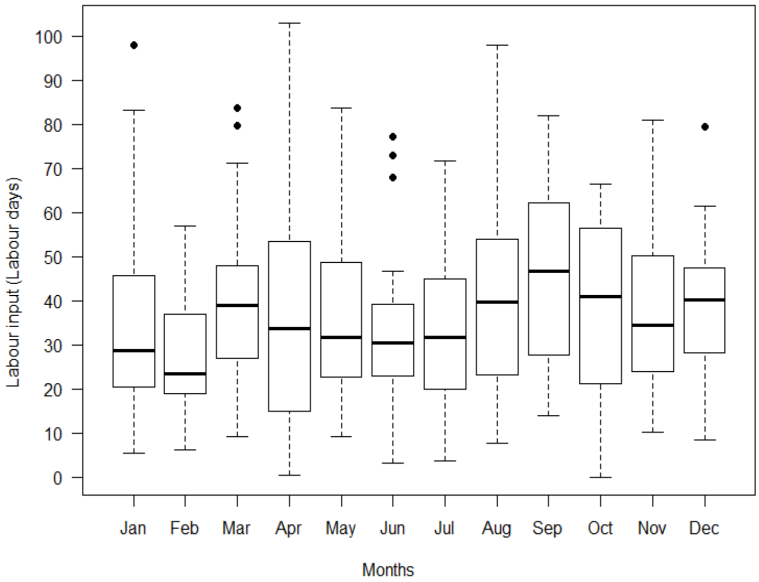

Figure 7. Total labour input over the year this includes family labour and hired labour. The black bar represents the median. The black dots are outliers.

3.4. Yield, crop productivity and labour input

Crop yields

The yield of the different crops varied among farms, as shown in Figure 9. The largest absolute yield differences were observed for coffee, banana and cassava. The median yields for coffee is 1700 kg, for banana it is 2700 kg, for maize it is 750 kg, for beans it is 560 kg, for cassava it is 800 kg and for "others" it is 500 kg. The data on which the plot is based are given in the appendix (Table 18).

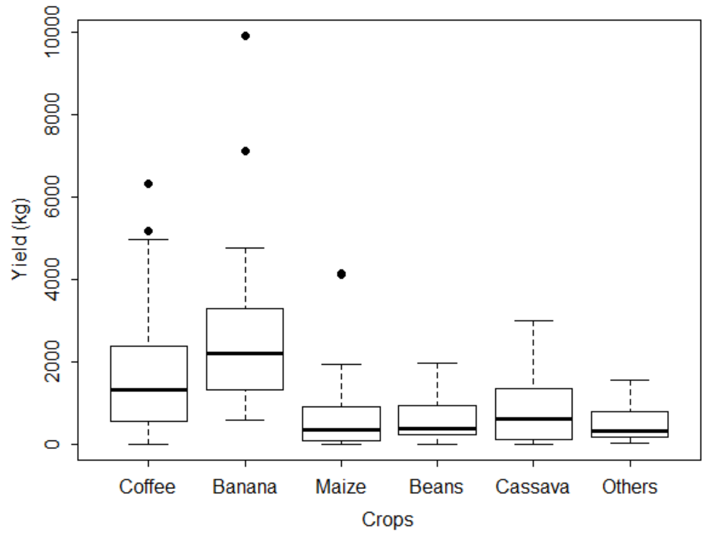

Figure 9. Crop yields per farm. The median yields for coffee is 1700 kg, for banana it is 2700 kg, for maize it is 750 kg, for beans it is 560 kg, for cassava it is 800 kg and for others it is 500 kg.

Crop productivity

The difference between crop productivity on the farms, defined as the fresh yield per hectare, is quite large as shown in Figure 8 and details are given in the appendix (Figure 19). For all crops some individual crop productivities are extremely high (appendix Table 18). The farms with these high values are: 7, 8, 15, 16, 21, 24, 37 and 45. Of these eight three (15, 24 and 37) have at least four of the six crops with high productivities. Farmer 15 has the highest values for banana (128 tonnes ha^{-1} an outlier not shown in Figure 8), maize (23 tonnes ha^{-1}) and other (45 tonnes ha^{-1}). Farmer 16 has the highest value for coffee which is 24 tonnes ha^{-1} and farmer 21 for beans (9.8 tonnes ha^{-1}). All of these high productivities are reached on very small plots.

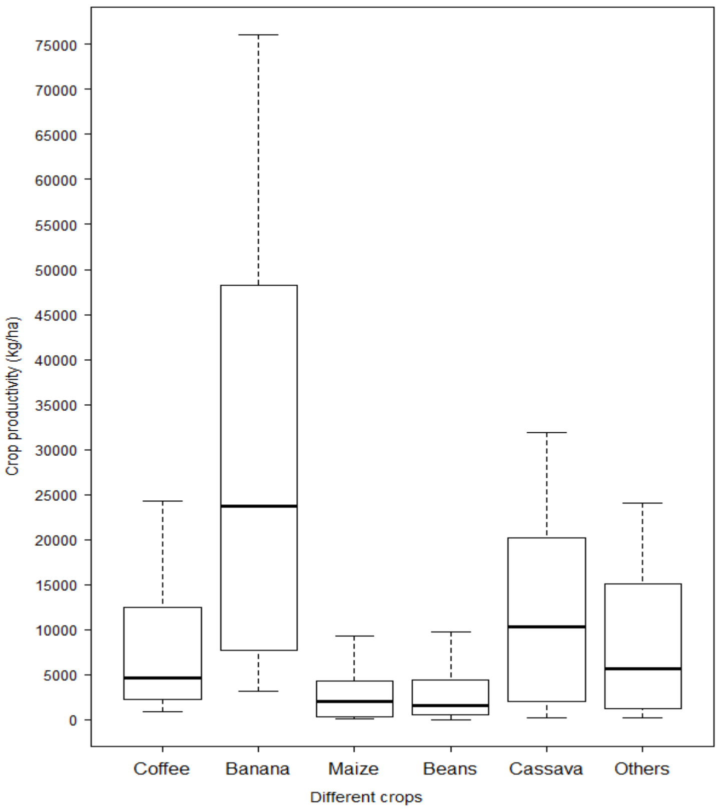

Figure 8. The variation in crop productivities (kg fresh weight/ha).

Table 11 shows the difference between crop productivities from literature and the data from the logbooks. As can be seen there is quite a large discrepancy between these numbers. The range of the values of the logbooks is extremely large. Beans have a very high median crop productivity. The difference between literature and acquired data may be explained by the fact that farmers in part also recorded the green biomass. Through using median values for maize and cassava an realistic crop productivity of what literature of Uganda indicates can be presented.

Table 11. Crop productivity range and median and labour input values from logbook data. The values from the literature are average values fresh weight crop productivities. The crop producitivty from the logbooks are recorded in fresh weight. Coffee logbook productivity have been recalculated with a dry berry factor of Table 3 to comparable with the literature.

Crops	Values			
	Crop productivity ($kg\ ha^{-1}$)		Labour input (labour day ha^{-1})	
	Literature	Logbook data	Literature	Logbook data
Coffee	600 - 1,250[1, 3, 7, 8]	385 - 10,930 (2,100)	283[3]	430
Banana	5,412 - 26,000[1, 3, 4, 7, 8, 11]	3130 - 127,850 (23,720)	327[10]	250
Maize	1,260 - 2,700[1, 6, 8]	80 - 20,255 (2,000)	235[5, 9]	140
Beans	420 - 640[1, 5, 8]	35 - 9,760 (1,570)	252[9]	350
Cassava	5,640 - 12,000[1, 2, 8]	205 - 31,880 (10,360)	540[9]	100

1. Nabbumba and Bahiigwa 2003;
2. Fermont et al. 2009;
3. van Asten et al. 2011;
4. Wairegi and van Asten 2010;
5. Fischler and Wortmann 1999;
6. Kaizzi et al. 2012;
7. van Asten et al. 2012;
8. FAO 2015;
9. Reckling 2011;
10. Bagamba 2007;
11. Nyombi 2010;

Labour input

Labour input for two of the five crops, banana and beans, is higher than the value in literature. For the three other crops the data from the logbooks indicate that less time is spent. The farmers indicated during the farmer meetings that cassava is low on their priority list which is reflected by the median labour input value of 100 labour day ha^{-1}. Cassava is only eaten in moments of dire need and has as such a low priority for these farmers. The high labour input values are on very small plots, so farmers can focus much of their attention. It is obvious from the data that the farmers spent much of their time tending to their crops, some had a higher priority and more labour input, especially the group other crops (Figure 10, Figure 20 and Figure 21 in the appendix).

There were a few farmers that spent exceptional amounts of labour in their crops (Figure 10). The black line is the median labour input of the farmers. The median values are for coffee 430 labour day ha^{-1}, banana 250 labour day ha^{-1}, maize 140 labour day ha^{-1}, beans 350 labour day ha^{-1} and cassava 100 labour day ha^{-1}. The outliers of the labour input similarly as for the crop productivity are from three farmers. Farmer 11 has the highest amount of labour input in coffee. Farmer 15 spends the most time on banana and farmer 45 has the highest labour input in all the other crops.

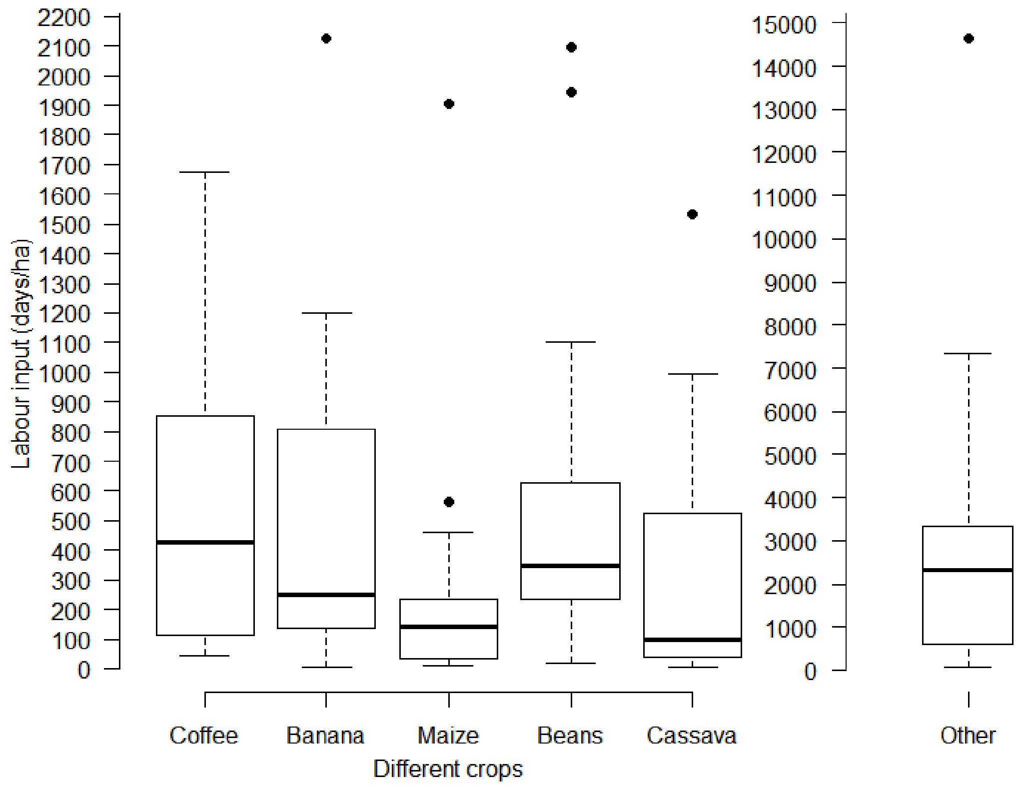

Figure 10. the variation in labour input per crop. Notice that "other" has a different Y-axis.

3.5. Logbook discussion

3.5.1. Logbook data in perspective

Household income

From Table 9 what can be noticed is quite some farmers are not solely dependent on the income of their farm. The question is if farmers with a low share from agriculture are willing to invest some of their income in their farm or that they would rather reduce their agricultural activities and just farm the land they have for some food and additional cash.

Farm size

The average farm size of 1.12 ha is rather small, much smaller than the average Ugandan farm of 2.5 ha (Bongers et al., 2015). The farm sizes have been measured during previous research and as such deemed correct (Semichon-Linard, 2014). This implies that the farmers that diligently registered all their activities are predominantly smaller farmers. From literature on farm typologies smaller farms either work very intensively or earn the majority of their income with off-farm labour (Bongers et al., 2015; Köbrich et al., 2003; Tittonell et al., 2005). The farmers that continue to cultivate and live of their land also prefer to have as diverse a farm as possible (Tittonell et al., 2005). In Figure 5B the crop allocations from the farmers are depicted and it shows actually no big differences between the farmers. Difference could be between richer and poorer farmers in crop choice or in the amount of land that each farmer has. The estimates are however a bit crude since the allocations were done based on 20 beans. Each beans thus represented 5 percent which is maybe too big of a unit for these diverse cropping farmers.

Labour allocation and input

Figure 6 show that there is quite a difference in the amount of time that the farmers spend on their land. It is striking that most households are quite equally distributed in the amount of labour that each family group does. What can be noticed is that the female headed households spend less time in total on their farms in comparison to the male headed farms due to a family labourer less. The average labour input over the year is quite constant (Figure 7). However the difference within each month still requires some attention, clearly not every month is as busy for every farmer. This raises the question how the labour input is registered. The labour that has been registered in the logbooks gives the days of *when* time was spent. However the chance is small that all farmers did it diligently after each day of hard work. Thus labour time, *the amount of hours*, might not be registered correctly. This affects also Figure 10 where the small acreages with relatively large amounts of time spent on the farm accumulate to huge labour inputs. The labour input figures from literature refer to Ugandan and Rwandan farms (Bagamba, 2007; Fischler and Wortmann, 1999; Reckling, 2011; van Asten et al., 2011). In some cases for labour input the logbook data is close to literature, e.g. maize (Table 11). Notice that for coffee and beans the labour input in literature is almost one and a half times as small where the opposite is the case for cassava. The chance that those labour inputs can be extrapolated on a larger scale is small since it is not profitable for the farmer to continue with the same high labour input on bigger tracts of land, due to amount of labour the farmers would need to hire (Harris and Orr, 2014; Rao and Chotigeat, 1981).

Yields and crop productivity

When looking at the figures from Table 11 the difference between crop productivities from literature versus what the data from the logbooks are is some cases two to three fold. As an extreme example the median productivity for beans is 1.6 tonnes per hectare which is three times what literature indicates (FAO, 2015; Fischler and Wortmann, 1999; Nabbumba and Bahiigwa, 2003). All the literature on the crop productivity is from Uganda and, when possible, the data from the central region was selected. The crop productivity values are all averages of one year of observations, only the paper of Fermont et al. (2009) is over two years. Depending on the crop, figures from the FAO either present the highest yields per ha or the lowest in comparison to other literature. This is because the FAO averages over whole Uganda which has places where crops grow better or worse than in these two regions. Other represents for these farmers in most cases sweet potato, Irish potato and in a single case (farmer 31) tomato, hence the relatively high productivity.

The high crop productivities could be a consequence of five things. First the crops that have the priority of the farmer might have been over represented and vice versa during the farmer meetings. Second scales are not present on the farms and thus the registration of yields was done in units that do not translate well into weights. Farmers would put their harvests in baskets, buckets, tins, cups or anything else that the family has to contain products. Although Table 2 covers all different types of possible units used by the farmers the accuracy of the weights remains dubious. Third the plots in the appendix of Figure 19 show inverse relations between crop productivity and land area for most crops. The bigger the amount of land is for a crop the lower the productivity is. All the plots in Figure 19 indicate an inverse relationship between productivity and land area (Ansoms et al., 2008; Benjamin, 1995; Carletto et al., 2013a; Carter, 1984; Rao and Chotigeat, 1981). Considering the small land areas for each crop the chance that during extrapolation mistakes are made are considerable. For example if one banana tree takes up one square meter for one of these farmers and this is extrapolated to one hectare it would mean that on each square meter one palm would be standing. This is simply impossible; hence the extrapolation of the productivities on these small plots to one hectare plots can lead to skewed crop productivities. The fourth reason could be that the plots of the farmers were not correctly measured or fields were missed. This could be the case for farmer 15 for example. She is able to produce around eight times more per hectare then what literature indicates. This could mean that she is not farming 0.2 hectare but 1.6 hectare. On all farms the crops where not spatially ordered in monocrop field but intercropped. This leads to the fifth reason; the relative yield total of intercropping could also affect the productivity of the crops. Which makes it possible to have no yield reduction with crops that are intercropped (Fischler and Wortmann, 1999; van Asten et al., 2011).

These crop productivities might in some cases be so high due to the small farm size and high labour input. In literature there is often a strong relation between high crop productivities on small plots of land with high labour input (Figure 19, Figure 20 and Figure 21) (Ansoms et al., 2008; Benjamin, 1995; Carletto et al., 2013a; Carter, 1984; Rao and Chotigeat, 1981). When crop productivity of the various crops is plotted against labour input for each crop the relations that are found are weak (Figure 22 in the appendix). For coffee and banana there are stronger relations compared to the other crops. It would mean the more labour input the higher the productivity. For maize a contrary relation can be shown indicating that the more time is spend on the crop the less productive it will be.

3.5.2. Using farmers logbooks

For this research the data from the logbooks was not collected but provided by IITA from previous research and ongoing research. The data has been checked on registering discrepancies and those farmers with incomplete and inconsistent logbooks have been omitted from the research. Logbooks have some advantages, it is less expensive, less reliant on long term revisits and it can measure several things at the same time (Clark et al., 2009). However it is clear that even though the farmers registered their activities it is not very reliable. Much of unreliability might be related to the greater participant burden of a constant response and compliance with possible reporting bias (Clark et al., 2009). Although much time is put in each logbook by each farmer, and surely the farmers did not purposefully play with the data. It is clear from the logbook data that crop productivity, labour input and land size are the three major discussion points. The biggest variation is within the crop productivity, this is however an accumulation of errors in land size, weight measurements and logbook registration.

The total acreages of the farms seem to be too small in relation to what the farmers produce. This brings the measurements that have been done into doubt. It is possible that not all fields have been measured or that fields were missed. The harvests depend on the weights that the farmers registered of their harvested products. Since these farmers have no scales but local units that can differ greatly another uncertainty compounds. There is also plenty of uncertainty on the registering part since this had to be done daily. The farmers not only had to register their harvests but also their activities with the amount of time spent. This is quite some work for farmers at the end of their day as can be seen in appendix A. There is quite a big chance that the farmers did the registration at more convenient moments. Losing accuracy because of estimations on what was done the previous day or days.

Solutions could be to spend a day with each farmer on his or her activities. This could clarify what the farmers should register and what the farmers do register. This could help in clarifying what the farmer would consider his or her labour time in only working on the field or also making a talk on the way to the field. Considering the units the best possible way to get accurate harvest weights is to provide farmers with scales. This could not only enhance the accuracy of the harvests, but could help also in how much is actually sold and could provide farmers with control on how much they actually have in respect to traders. In respect to how the logbooks are kept checks could be built in by meeting these farmers individually at least monthly and spent a day talking their logbooks through. It remains however a labour intensive activity and the rewards should be clear for the farmers such that there is continued commitment.

4. Model outcomes

The results of the previous chapter show that some data received of some farms are not reliable. In the upcoming chapters these farms are not excluded. For each farm the farm specific data from the survey, logbooks and the additional data collected during the farmer meetings were used as input in the optimization model. This involves amongst others land use, annual labour input, crop productivities, prices and the energy requirements of the household. In the next chapter the results will be show of the model run on that data. First the current situation is used to benchmark the base scenario for income, food security and food self-sufficiency. The other scenarios were compared to the base scenario and focus on income, food self-sufficiency, food security, land and labour allocation. Finally, a sensitivity analysis was done and the model and the results are discussed.

4.1. Benchmarking the model

The base scenario was used to benchmark the model to the current situation. The base scenario was compared to the current situation for the three aspects food self-sufficiency, food security and income. In this order the influence of prices on the results increases and the importance of land allocation and productivity reduces. In theory there should be a 1:1 relation between the modelled (base) and current situation depicted with the dotted lines in Figure 11. The model underestimated food self-sufficiency compared to the current situation (Figure 11A). For the predictions of the food self-sufficiency situation of the farmers the model preforms reasonable well. For food security the model both under- (23 farms) and over- (3 farms) estimates the current situation (Figure 11B). The regression line however does not differ much from the 1:1 line according to the slope inference test with a P-value of 4.4409e-16. Tropsha (2010) has formulated criteria that ensure the predictability of regression models. Of the four criteria that are formulated the R^2 criteria of larger than 0.6 is passed and one on the k value is passed half. The k value of the regression function is outside the boundaries of $0.85 \leq k \leq 1.15$ however if one looks at the upper limit of the regression line which is 0.87 then it falls just between the lines. So not all conditions of Tropsha (2010) are met since the model was not cross validated.

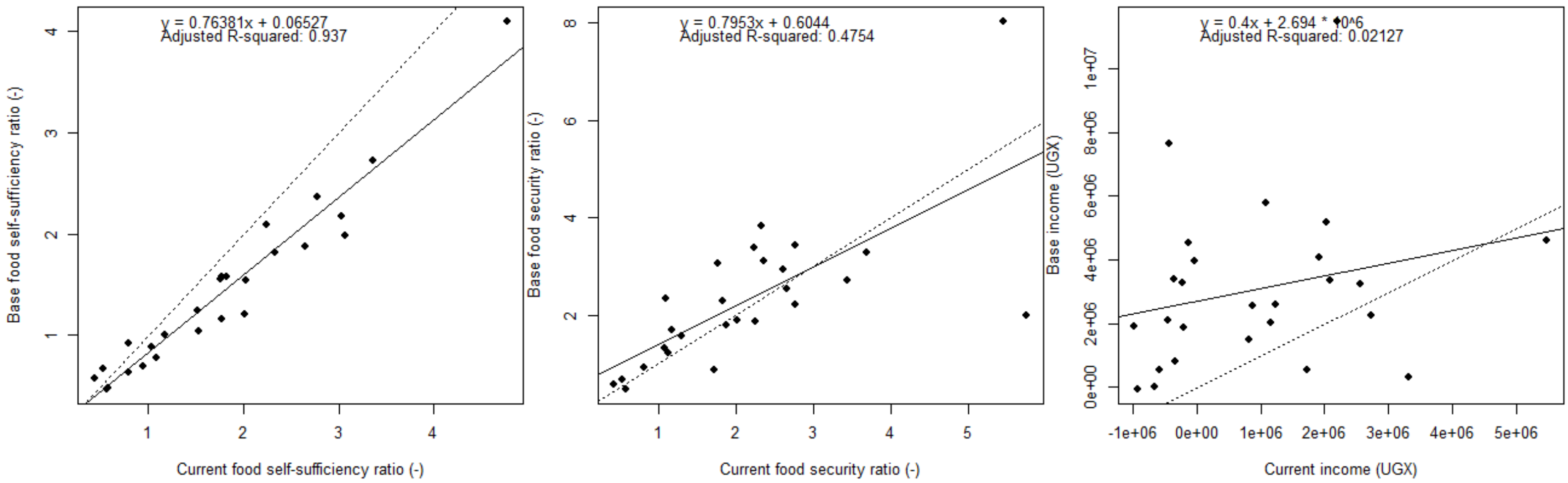

Figure 11. These figures show the benchmarks of the current situation of the farmers versus the results of the base scenario. The black solid lines represent the relation between the current situation and the modelled base scenario. The dotted line represent the 1:1 line. (A) Food self-sufficiency benchmark showing the relation of the current and the base scenario. The r^2 value is 0.937, which shows a strong relation. (B) The current food security situation in relation to the results from the base scenario. The r^2 value is 0.4878, which shows a weak relation. (C) The income benchmark showing the base against the current income. The r^2 value is 0.02127, which shows a very weak relation.

Figure 11B shows a weak relationship between the model and reality, although the trend follows the 1:1 line, for individual farms the results deviated substantially. The predictability of the regression line for food security by the model is worse than for FSS. The regression line however does not differ much from the 1:1 line according to the slope inference test with a P-value of 5.8709e-5. However on all criteria of Tropsha (2010) the model fails. The only difference between the FS and FSS calculations is that the income of coffee comes into play. For the food self-sufficiency calculations only the crops that were consumed for food were considered. The farmers sell the coffee only and this money can be used to buy additional food. For 6 farmers the model underestimates the amount of food that was bought by the household with the revenues of the coffee production. The two outliers in Figure 11B are household numbers 24 and 52. Farmer 24 has been overestimated by the model which could indicate that the prices that he gets for his coffee are much lower then the current market prices. the opposite is the case for farmer 52 he sell his coffee for a much higher price then what the model as a price has. The results are that farmer 24 is capable of buying much more food in the model and farmer 52 much less.

Farm income was underestimated for three farms for all other farms the income was overestimated (Figure 11C). The over estimation of the model is due to uncertainties; the price per kg product paid by the traders, the amount of kg sold and the compounding uncertainties from the logbooks. The products that were sold in the base scenario were based on the individual crop productivities. The current income was based on the earnings that each household registered from the farm products that they had sold. Here it was not clear the quantity of the sold product and the relating price per kg. The over estimation of the income is however mostly due to higher wholesale price that has been used in the model for the sale of the farmers products.

4.2. Farm income in the three scenarios

For most farmers the scenarios predict positive incomes (Figure 12). The constrained and the free scenarios were meant to improve the economic situation of the farm while taking care of food security. For farmer seven the constrained scenario was infeasible. Due to the food security constraints some farmers have a negative farm income. These farmers needed to buy more food than that their farm provided in terms of food and cash from agricultural activities. Overall the average income in the constrained and free scenario increases, with the income in the free scenario being much higher than in the other scenarios (Table 19 appendix).

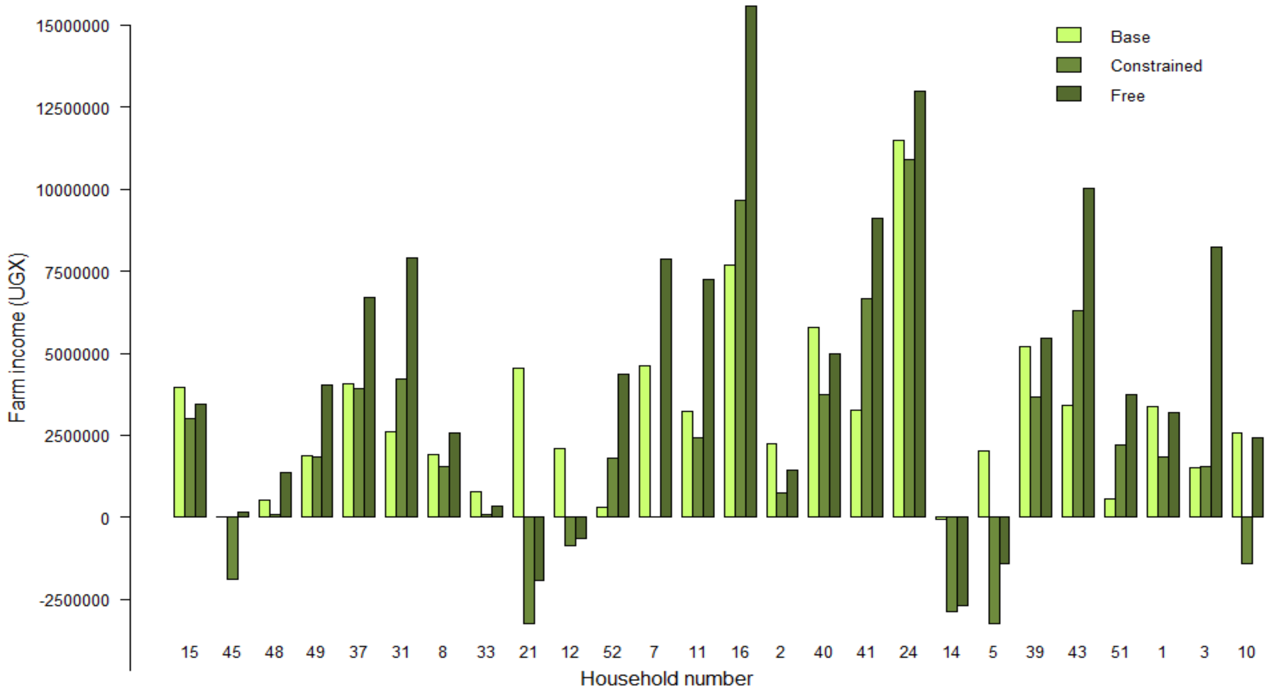

Figure 12. Income in the base, constrained and free scenarios in (UGX). The order of the numbering is based on the size of the farms.

Comparing scenarios is however difficult due to differences in household incomes (Figure 12). In Figure 13 the base scenario representing the current situation was set to zero such that effects of the constrained and free scenario could be compared. The average income is positive in all scenarios: 3.1 million UGX in the base scenario, 2 million UGX in the constrained scenario and 4.5 million UGX in the free scenario (Table 18 in appendix). Six farmers increased their income in the constrained scenario and 13 farmers in the free scenario compared to the base scenario. The majority of the farmers (18) had no improvement and even a reduction in their income compared to the income from the base scenario. For 8 farmers the income in the free scenario was also not positive, it was however a less bad income then in constrained scenario. In general the constrained scenario negatively affected the income and the free scenario had a positive effect on the income. However, for individual farmers the scenarios showed widely varying income effects (Figure 12, Figure 13 and Table 18 appendix)

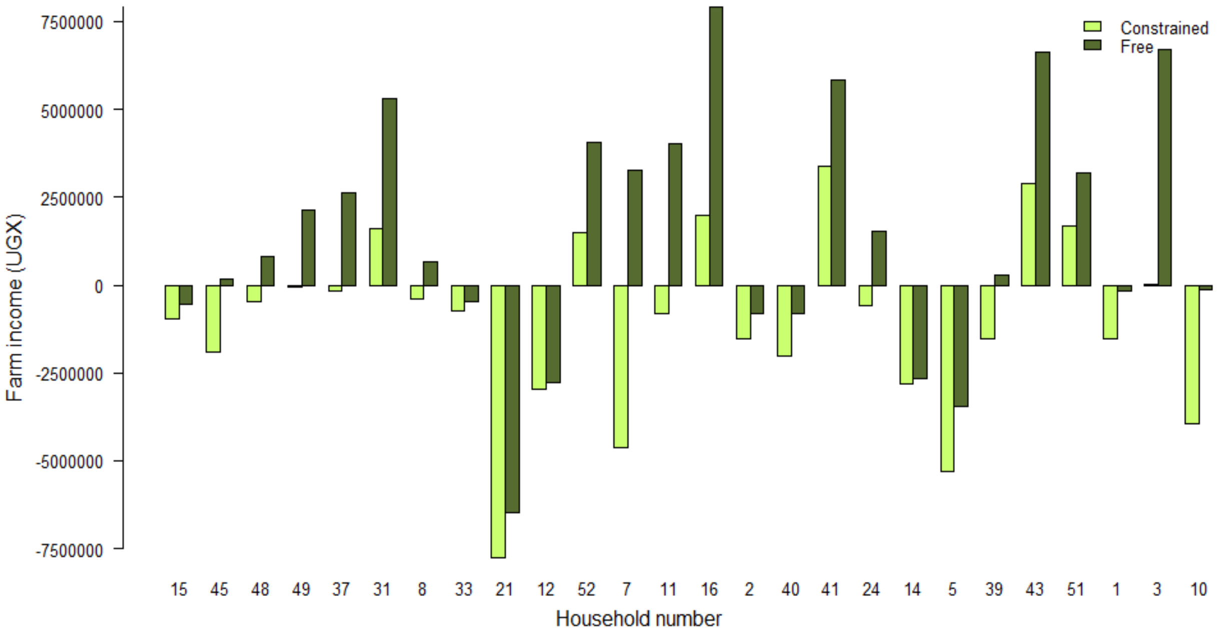

Figure 13. Modelled income in the constrained and free scenario compared to the base scenario. The base is zero and the constrained and free scenarios additive or reducing income in UGX. The order of the numbering is based on the size of the farms.

4.3. Food self-sufficiency and food security in the three scenarios

Figure 14 shows the food self-sufficiency situation of the farms. Below the red line means that farmers were food self-insufficiency and the farmers with a bar above the line were food self-sufficient. What can be noticed is that in the base scenario 35% of the farmers did not produce enough energy to sustain the household needs. When the constraints for food security are added in the scenarios most household become food self-sufficient. For some farmers the free scenario has no added benefit compared to the constrained scenario (14, 33 and 24). There are two farmers (14, 5) that remain food self-insufficient through out the scenarios. Notice that farmers in the free scenario not necessarily produce much more energy compared to the constrained scenario. There is also a clear distinction in that some farmers (1, 12 and 5) cannot improve their situation much more whereas other farmers (3, 16, and 31) can improve their production three fold. For household seven the constrained scenario was infeasible.

The calculations on which Figure 14 and Figure 15 are based are the formulas from Chapter 2.3.1. These calculations are purely based on the amount of energy that is produced on the farm. therefore they are irrespective of the food basket. The spikes for the free scenario are hence mostly based on the energy that banana provides to the household. The formulas on which the graphs are based are not similar to what has been used in the LP model were the food basket has been considered.

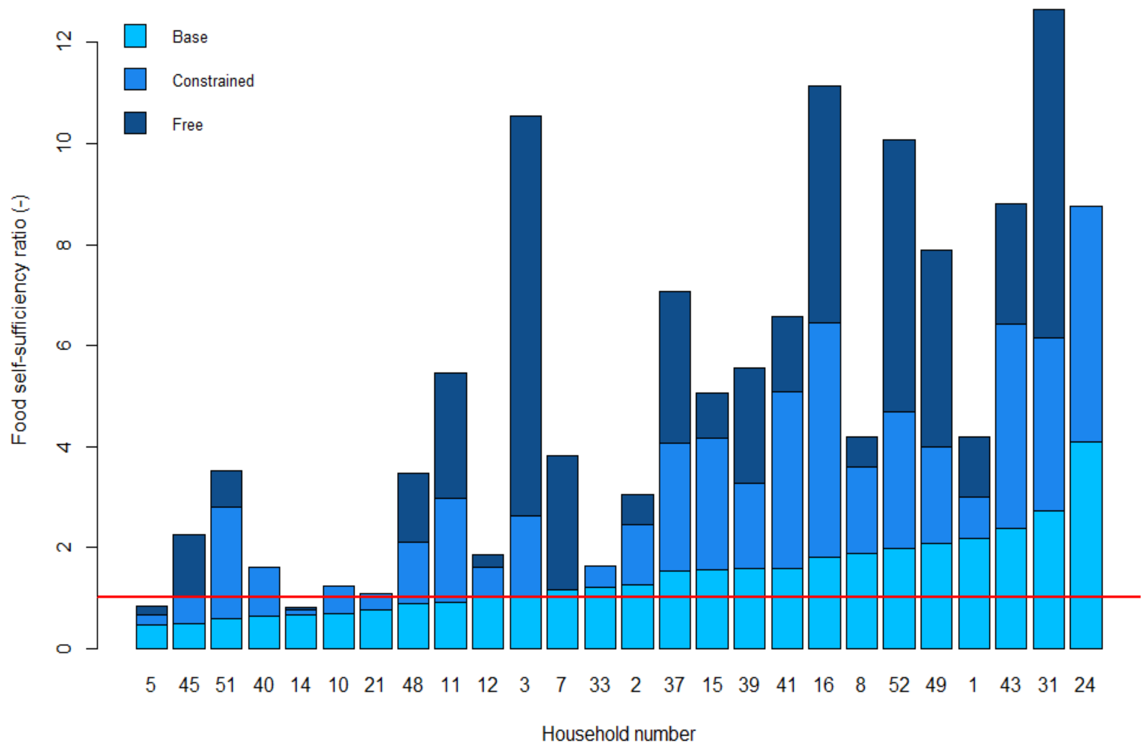

Figure 14. Calculated food self-sufficiency in the three scenarios. The household numbers are sorted on the FSS ratio of the base scenario. The red line indicates the food self-sufficiency ratio of 1.

As shown in Figure 15 the maximum FS ratio is higher then the FSS ratio, as cash can be used to uy food. Below the line means food insecurity and the farmers with a bar above the line are food secure. In the base scenario six of the 26 (23%) farmers were food insecure. From the six farmers that are food insecure only two remain food insecure (14 and 5). Food some farmers the free scenario does not provide any additional benefit compared to the constrained scenario. The model in the free and constrained scenario both improve the food security of the household.

Table 12. Average FSS and FS ratios for the scenarios.

	Current	Base	Constrained	Free
Food self-suffiency	1.8	1.4	3.1	4.8
Food security	2.1	2.3	4.0	6.5

Notice that income from coffee has some major effects because the order of the farmers is different as can be seen in the order of Figure 14 and Figure 15 and through the average ratios in Table 12. The same observation applies for food security as for food self sufficiency; some farmers can improve tremendously while other farmers are close to their maximum.

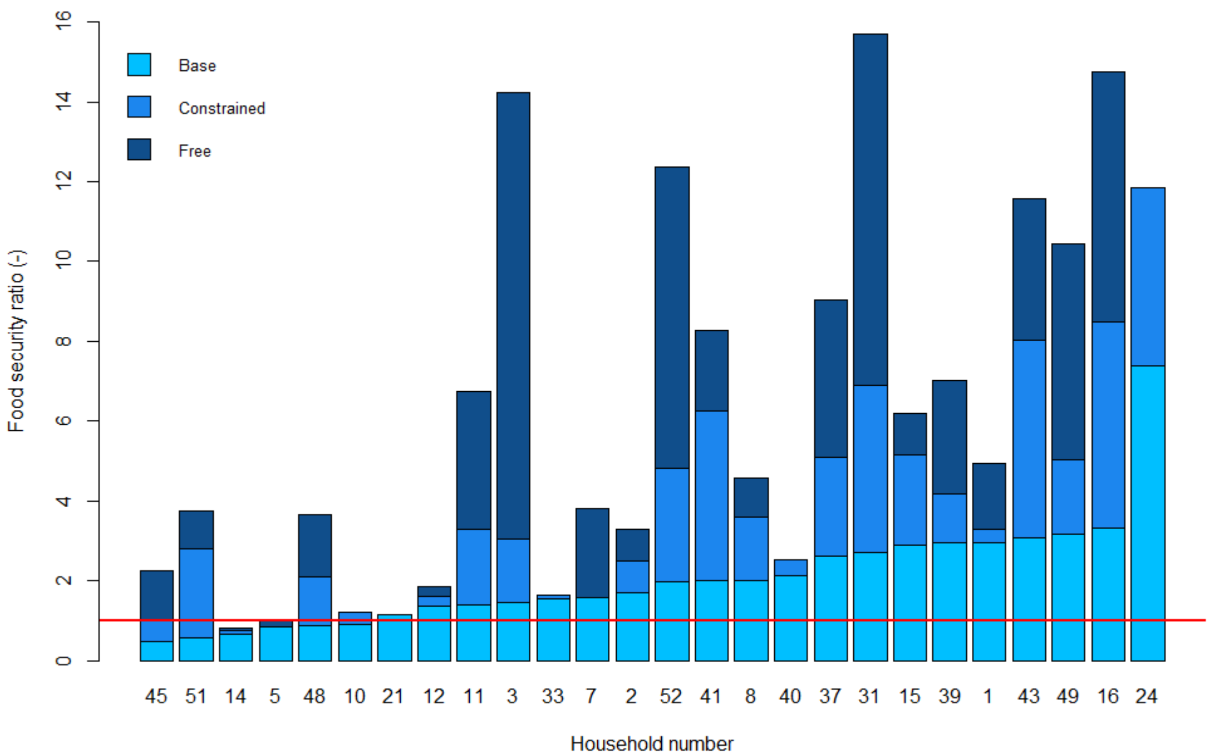

Figure 15. Calculated food security in the three scenarios. The household numbers are sorted on the FS ratio of the base scenario. The red line indicates if farmers are food secure.

4.4. Land allocation in the three scenarios

The land allocation for the farmers in the scenarios is dependent on the constraints that were imposed. The effects of these constraints can be clearly seen in Figure 16. Most farmers have just the minimum of coffee in the constrained scenario. Farmers indicated during the meetings that the allocation of land to coffee and beans was essential. Equally so the amount of land allocated to cassava is clearly much more than in the base scenario which reflects the food security constraint. For the food security constraint the assumption was through the food basket that farmers were not buying cassava in the constrained scenario. Therefore to produce just the 5% of their diet they need

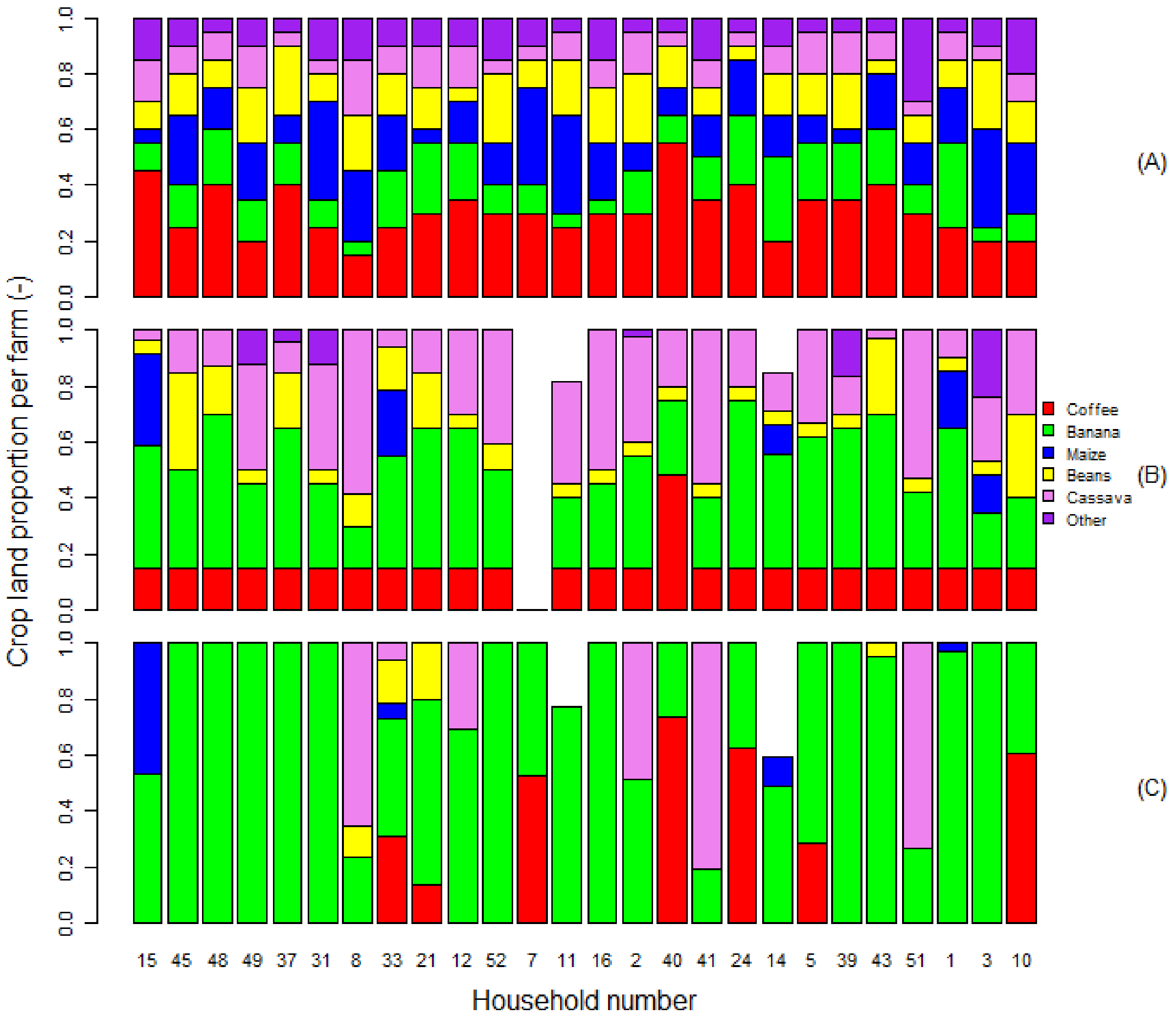

Figure 16. The optimized land allocation per farm. The figure is ordered on farm size. (A) Shows the current land allocation. (B) Shows the land allocation based on the constrained scenario. (C) Shows the results of the free scenario. Household number 7 has an infeasible solution and therefore no results in the constrained scenario (B).

to allocate more land to cassava (Figure 16). The amount of land allocated to beans was variable between farms. Almost no land was allocated to maize and others, with only five farmers being productive enough to render maize and others profitable. In the free scenario most farmers produce banana. Some farmers were simulated to produce coffee, beans or cassava. The crop productivity of these crops for those farmers was high enough to be profitable when grown next to banana. There are two farmers (11, 14) who cultivate less area than the area than they have. This indicates that their farms are food secure even without the full use of their area.

Figure 17 shows the trends of land allocation that the model calculates for the different scenarios. The black bars show the median of the land allocated to that specific crop of all the farms. The boxes around the bar represent the second and third quantile around the median. The black bars with no boxes indicate that either statistically the allocation to crops is zero hectares or that the differences between the crop allocations were so small that only a line is visible. Figure 17A shows the current land allocation. Coffee is in this case the crop to which most land is allocated. Figure 17B provides insight in what the land allocation was for the constrained scenario. Coffee in the constrained

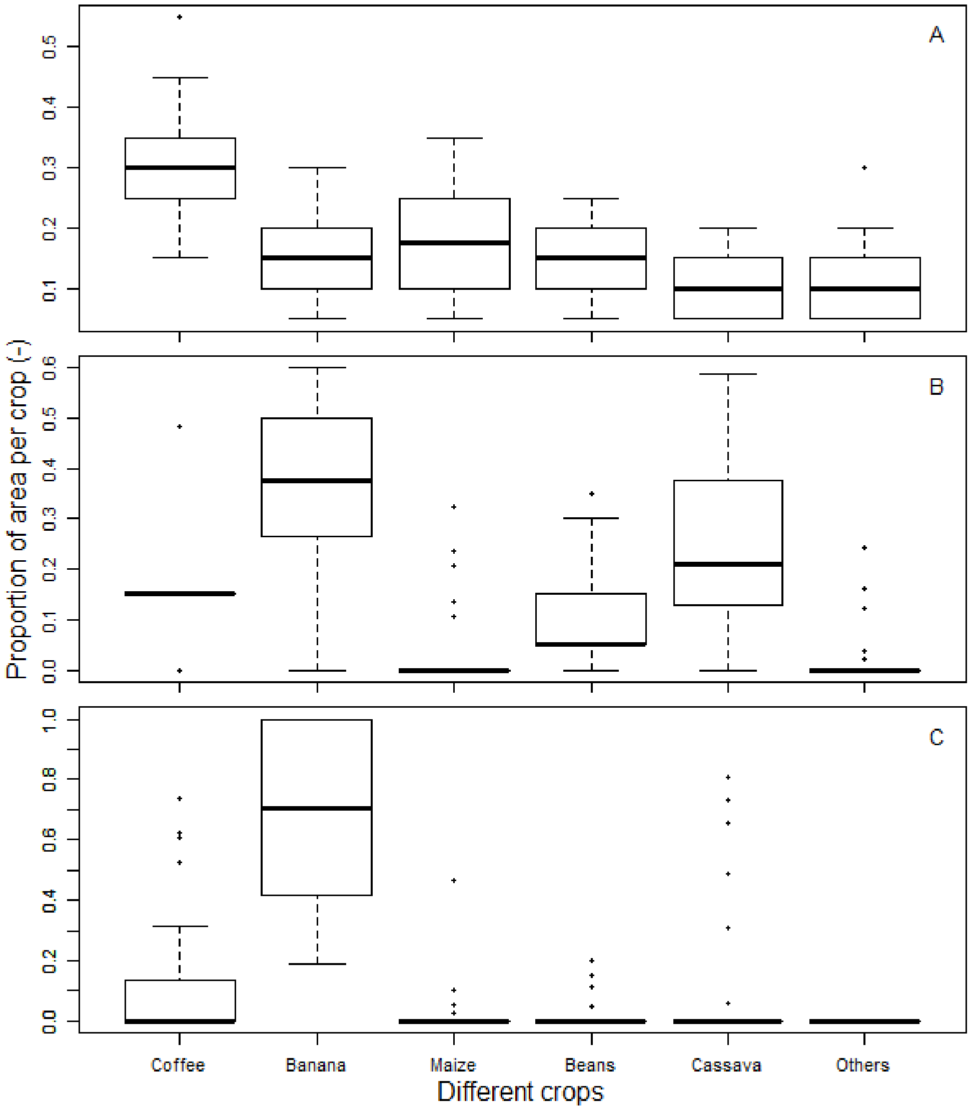

Figure 17. Land allocation trends for the various scenarios. (A) Is the current land allocations and also used by the base scenario. (B) Is the land allocation based on the constrained scenario. Farmer 7 has been discarded in this figure since he has no values. (C) The bar plots show the results from the free scenario.

scenario has a median value due to the constraint and the lack of added value for the farmers in profitability compared to banana in that scenario. Of the annuals, beans and cassava are the crops that are preferred by the model. Beans have no variation due to the constraint for beans being the median and the model allocating more land to beans because of the profitability and the constraint in the scenario. These cases are caused by the land constrains in the constrained scenario. The trend in the free scenario is that most land is allocated to banana and some land is allocated to coffee with some additional exceptions (Figure 17C). Banana has for both the constrained and free scenario the highest land allocation because of the high profitability.

4.5. Labour

The total labour in the scenarios has been constrained in the base and in the constrained scenarios. In the free scenario there has been only a constraint on the family labour. Although in most cases income increases from base to constrained to free, labour input generally decreases (Figure 18). Most of the labour was already done by the household members (Figure 6) and this continues to be so since most households do not hire any labour (Table 13). There are three farmers that hire labour

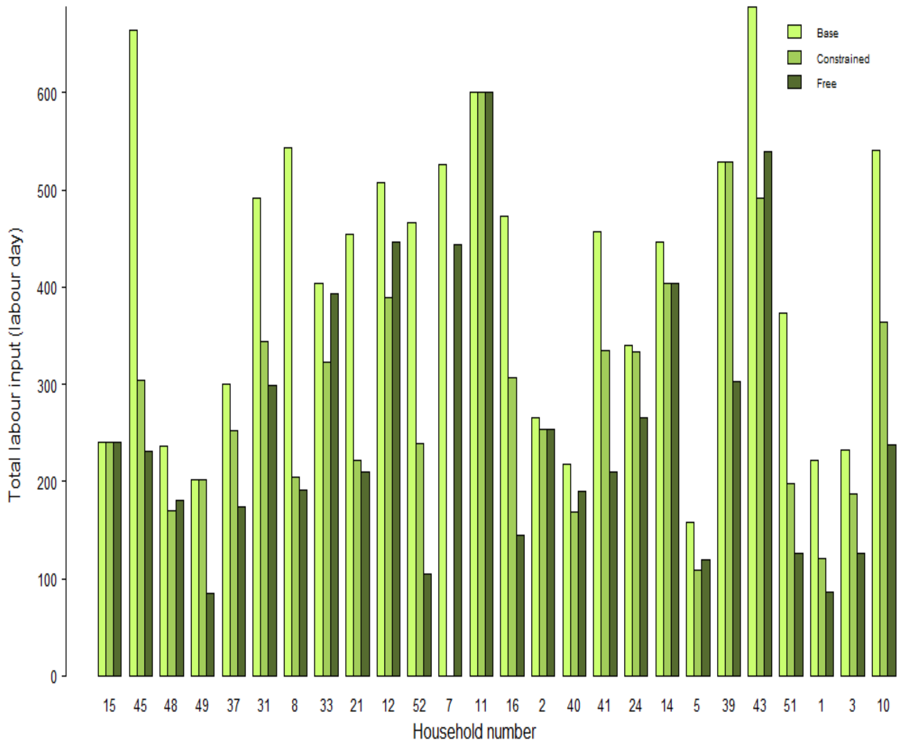

Figure 18. Total labour input from the three scenarios. The households have been sorted on their farm size.

Table 13. Total number of labour days with hired labour.

	Hired labour (labour days)		
Household number	Base	Constrained	Free
1	15	0	0
2	12	0	0
3	45	0	0
5	16	0	0
7	82	0	0
8	54	0	0
10	0	0	0
11	0	0	0
12	3	0	0
14	44	0	0
15	0	0	0
16	86	0	0
21	1	0	0
24	75	68	0
31	147	0	0
33	10	0	0
37	48	0	0
39	164	164	0
40	39	0	12
41	116	0	0
43	14	0	0
45	26	0	0
48	2	0	0
49	10	10	0
51	180	5	0
52	158	0	0

in the constrained scenario; numbers 39, 49 and 51. The labour demand of farmers 39 and 49 in the constrained scenario does not decrease compared to the base scenario. For farmer 51 the labour demand decreases sharply however hiring labour remains necessary. In the free scenario most of the labour is done by the family, only farmer 40 needs to hire labour, indicating that it is profitable for him to hire labour.

4.6. Sensitivity analysis

The parameters sensitivity in the constrained scenario was tested. The parameters that were analysed were farm size, total amount of labour days, labour input, crop productivity, whole sale prices and retail prices. The sensitivity analysis was done from 90% to 110% of the original value. In Table 14 the relative change over the intervals of 99% - 101%, 95% - 105% and 90% - 110% can be seen. Values around 0% mean that there are no changes and that the parameter has no effect on the simulated income. If the change is between 0% and 20% the parameter has a fairly linear effect on the simulated income. If the parameter has an effect of above the 20% then it has a major effect on the income of the farm. Income values that are zero indicate infeasible outcomes from the simulation. There is symmetry in the values that are infeasible, with the highest whole sale price and the lowest retail price for other resulting in a zero income. The income percentages contain a few zeros. These values indicate no change as for labour input for maize and beans and the whole sale price of maize. The values for other in whole sale and retail prices could not be estimated due to the infeasibility. In the retail prices cassava shows no change either and this is cause by the constraint that the household does not buy cassava.

Table 14. Results of the sensitivity analysis on parameters with its effect on the average of all farm incomes in UGX and % is shown.

	Income change (UGX)						Income change (%)		
Parameter	90%	95%	99%	101%	105%	110%	99-101%	95-105%	90-110%
Maximal land area	1,503,218	1,764,343	1,970,792	2,073,947	2,277,841	2,525,895	5.2	29.1	68.0
Total amount of labour days	1,971,195	1,997,681	2,017,468	2,022,972	2,025,381	2,028,393	0.3	1.4	2.9
Labour input	-	-	-	-	-	-			
Coffee	2,039,035	2,029,614	2,023,818	2,020,921	2,015,126	2,007,807	-0.1	-0.7	-1.5
Banana	2,065,753	2,044,465	2,026,752	2,018,037	1,999,972	1,977,379	-0.4	-2.2	-4.3
Maize	2,023,664	2,023,018	2,022,500	2,022,240	2,021,719	2,021,064	0.0	-0.1	-0.1
Beans	2,027,310	2,024,840	2,022,864	2,021,876	2,019,900	2,017,430	0.0	-0.2	-0.5
Cassava	2,039,579	2,030,709	2,023,999	2,020,758	2,015,099	2,008,515	-0.2	-0.8	-1.5
Other	2,028,502	2,025,267	2,022,925	2,021,826	2,019,760	2,017,397	-0.1	-0.3	-0.5
Crop productivity	-	-	-	-	-	-			
Coffee	1,932,976	1,977,673	2,013,430	2,031,309	2,079,095	2,145,296	0.9	5.1	11.0
Banana	1,703,232	1,859,107	1,987,444	2,057,262	2,196,143	2,363,440	3.5	18.1	38.8
Maize	2,016,065	2,019,162	2,021,733	2,023,004	2,025,678	2,029,186	0.1	0.3	0.7
Beans	1,993,072	2,007,971	2,019,468	2,025,246	2,036,514	2,050,108	0.3	1.4	2.9
Cassava	1,870,556	1,946,705	2,007,057	2,037,688	2,100,539	2,178,731	1.5	7.9	16.5
Other	2,006,676	2,014,523	2,020,800	2,023,939	2,030,216	2,038,063	0.2	0.8	1.6
Whole sale price	-	-	-	-	-	-			
Coffee	1,932,976	1,977,673	2,013,430	2,031,309	2,079,095	2,145,296	0.9	5.1	11.0
Banana	1,887,126	1,951,253	2,006,169	2,038,570	2,103,371	2,184,372	1.6	7.8	15.8
Maize	2,018,068	2,020,196	2,021,935	2,022,804	2,024,543	2,026,716	0.0	0.2	0.4
Beans	2,017,117	2,019,743	2,021,844	2,022,895	2,024,996	2,027,622	0.1	0.3	0.5
Cassava	1,891,706	1,956,890	2,009,037	2,035,734	2,091,022	2,160,272	1.3	6.9	14.2
Other	2,014,577	2,018,474	2,021,590	0	0	0	0.0	0.0	0.0
Retail price	-	-	-	-	-	-			
Banana	2,063,210	2,041,643	2,025,817	2,018,939	2,005,217	1,988,064	-0.3	-1.8	-3.6
Maize	2,045,710	2,033,977	2,024,691	2,020,048	2,010,932	1,999,790	-0.2	-1.1	-2.2
Beans	2,068,863	2,045,485	2,026,893	2,017,846	1,999,751	1,977,133	-0.4	-2.2	-4.4
Cassava	2,022,370	2,022,370	2,022,370	2,022,370	2,022,370	2,022,370	0.0	0.0	0.0
Other	0	0	0	2,017,011	1,995,576	1,968,782	0.0	0.0	0.0

The increase and decrease of the size of the maximal land area that the farmers can cultivate has tremendous effects on the income. In the interval of 20 percent the income increases with 68%. For the total amount of labour days there is a slight increase. An increase in income is interesting since for most farmers the total amount of labour decreases in the constrained scenario in comparison to the base scenario.

Some patterns can be distinguished in the income changes. Bananas contribute most to the farmers. An increase in crop productivity can increase the income by almost 20% from the current situation. The increase in price has an additional beneficiary effect. Income is negatively affected the most by a price decrease of banana. Maize and beans are the two crops which are in general least affected by the variations of their prices. However both crops differ in the effects that they produce. Their effects are such that for every increase or decrease maize makes, beans double that, except for wholesale prices. It is interesting because beans are, for a part, forcibly cultivated in the model due to the constraint. Even though each farmer has to produce beans farmers still need to buy extra beans. If the price rises this affects their income especially due to its high whole sale price. In general the income of the farmers is positively affected through increases in crop productivity. Crop productivity increases for cassava affect the income by 16.5%. This could be due to two reasons; cassava can be sold or land under cassava cultivation can be reduced. This land that would become free could then be used for the cultivation of banana. Cassava does however also influence the income quite drastically when the whole sale price increases. The results from Figure 17b are strengthened when the price increases.

An increase in the labour days that a farmer can spend has a positive influence on income. However the increase of the labour input necessary for each crop does not have a positive effect. It would actually mean a decrease in efficiency of the farmer in cultivating that particular crop. The additional time needed for tending to that crop reduces the possibility of working on another crop or increases the need for hired labour.

Thus an increase in total area, total amount of labour and an increase of crop productivity parameters had a positive effect on the simulated income of the farmers. An increase of the labour input would have negative effects on the income of the farmers. The inverse however would only slightly increase the income. Prices of products have an expected effect on the income; the higher a selling price (whole sale price), the higher income and vice versa for buying prices (retail prices).

4.7. Model discussion

Benchmarks

The model does a fairly good job on predicting FSS, FS, however for income the predictability is bad (Figure 11). Although the correlation decreases from FSS to FS it still is able to predict the farmers FSS and FS reasonably well. For FS and FSS the model slightly overestimates the current situation. The overestimations are related to assumptions that all the food that is produced is eaten and none is sold.

The predictability of the base scenario for the current income is not accurate because of several reasons. The income of the current situation is based on what the farmers registered as revenue of their sold products. What is not known is how much is sold of the products that the farmers harvested additionally to that the price per kg is also not given. This builds further on the results of the logbook data on the uncertainty of weights of the units used. The income of base scenario is based on the selling of all products. The farmers do not sell everything because they eat too therefore the relation indicates that the farmers have a lower current income then is modelled in the base scenario.

Model results

The model provides for the food security in the constrained and free scenario of the farmers through the imposed constraints. This is done at the expense of the income and hence some farmers have negative income figures (Figure 12) which is less than in the base scenario. When observing the FSS and FS not all farmers are food secure. This contradiction is caused by the calculation of the FSS and FS situation (Figure 14 and Figure 15). Both are based on the amount of calories that are produced on the farm which in both cases means that banana is the major contributor to those values. Banana fulfils the energetic needs for the FSS and FS calculations. In the constrained and free scenarios food security was based however the food basket. The food basket constraints provide a diverse diet for the farmers (Figure 16 and Figure 17) (Geniez et al., 2014; Rufino et al., 2013). The nutritious aspect of the food products have not been taken into account however they might be included through the consumption basket (Table 3) (Chibuye, 2014).

A small but for some farmers still significant portion of the household consists of children (Table 9). In the model the energetic needs of the children are mixed with the adults with lower energetic needs based on averages. This leads to a slight overestimation or underestimation of the energy need depending on the age of the children. If the children are below 12 then their caloric needs are overestimated and vice versa. This over or underestimation of the caloric needs of the household due to the uncertainty of the age of the children needs to be kept in mind (Brody, 1999b).

Because the model allocates most of the land to banana and cassava the labour input necessary for these farms was reduced tremendously (Figure 18). Since these crops were in most cases not that intensively cultivated it might actually that the labour input necessary for these crops increases because the farms will depend more on their production.

Land allocation

Figure 16 shows that annual crops are, according to the free scenario, not very necessary. In the constrained scenario cassava is by far the dominant annual crop by amount of land (Figure 16). Even though the food basket demands only 5% of the diet consists of cassava, cassava's dominance is mostly due to the relatively low productivity for some farmers (Table 3 and Table 17). The figure shows also that two farmers (11, 14) are cultivating less land that they have. The reason for this is that farmer 14 depends on hired labour which according to the model is too expensive to hire. Farmer 11 did not hire labour in her current situation therefore we assumed that she has not the availability to hire any. For 14 the price of labour is so high and the amount of labour that the family can supply is not enough to cultivate all of the household's land. Both farms are in the constrained situation food secure through buying food at the market. Farmer 11 is able to become profitable in the free scenario with the food security constraints with the cultivation of banana (Figure 12, Figure 15 and Figure 16).

From the annual crops maize and other are the crops which most farmers do not need to cultivate (Figure 17). Only the farmers that have very high productivities for maize and other are able to continue cultivating these crops (Figure 16). However for most farmers the productivity is much lower than those of banana and cassava, meaning it cannot be more beneficial than the constant production of banana.

5. Farmer discussion

The results from the logbooks showed that the group of farmers was rather diverse. The results of the LP model from the base, constrained and free scenarios were also not that straight forward. This chapter tries to clarify the results from the scenarios and give some insights into why some farmers do well and others less so. We investigated the results of the simulations of the model on six farmers. The six farmers are 3, 14, 21, 24, 31 and 43. These are equally split into female and male headed households, districts and cover the spectrum of farm sizes (Table 15).

Table 15. Details of discussed farmers are shown. HHN is the household number, G stands for gender, ha is used to indicate the amount of land each farmer cultivates in hectare. Farm income is used to indicate if the farmer has a negative or positive farm balance with + being positive and – negative. Farm revenue % stands for the amount of income that the household recieves of the farm. For lab input, the total labour input, crop prod, crop productivity and for FSS and FS the same symbols are used. Low (L) , average (A) high (A+) or average low (A-) and high (H) Not means not FSS or FS. For FSS and FS low means just FSS or FS. Land allocation constrained is used to indicate which crops these farmers grow next to the expected due to the constraints crops of coffee, banana, beans and cassava. Land allocation free focusses on which crops these farmers grow in the free scenario. Land allocation constrained and land allocation free are used to indicate which crops are grown. For coffee (C), banana (Ba), maize (M), beans (Be), cassava (Ca) and (O) for others. Labour is used to indicate if the farmer will hire labour or not or if its constrained in doing so for the constrained scenario.

HHN	G	ha	Farm income	Farm revenue %	Lab input	Crop prod	FSS	FS	Land allocation constrained	Land allocation free	Labour
3	F	4.1	+	80	L	L	L-H	L-H	M+O	Ba	-
14	F	1.5	-	20	A+	L	Not	Not	M	Ba+M	Constraining (costs)
21	M	0.5	-	40	A	H	Not –L	Not – L	-	C+Ba+Be	-
24	M	1.3	+	50	A-	H	H-H	H-H	O	C+Ba	Hires
31	M	0.45	+	70	A+	H	A-H	A-H	-	Ba	-
43	F	1.8	-	20	H	A	A-H	A-H	-	Ba+Be	-

Farmer 3 is one of the farmers that can greatly improve her farms' production. She has the second largest acreage in this study, with 4 ha. Although her income does not increase much from base to constrained scenario due to the cultivation constraints, in the free scenario it greatly increases because of the cultivation of only banana (Figure 16). This is important for her since almost 80% of her income comes from her farm products (Table 9). Her labour input although low can decrease through the different scenarios which would free her up to do off-farm labour. The constrained scenario continues to let her cultivate the same amount of crops, however in different proportions (Figure 16). It is striking to see that, while in most cases other and maize are the categories which get the least land or no land allocated, she can continue to cultivate them. This is due to her low labour input for both maize and other (Table 18). In contrast to that, her crop productivities are on the lower end of the crop productivity spectrum of Table 11. If her crops would become more productive, her land allocation would not change considerably. The exception is that if the productivity of maize increases, her land division would change to favour cassava and other. The change of the allocation could be explained through the low labour input for cassava and the higher profitability of others. It is clear from Figure 14 and Figure 15 that she has much to gain in FSS and FS.

While it might not be completely realistic for her to grow 4 ha of banana the possibility to increase its acreage might do much good as can be seen in Figure 16.

Farmer 14 is a household that did not become food secure through the proposed scenarios. Together with farmer 5 they were the only two that did not become food secure of the initial six that were food insecure (Figure 15). It is a female headed household. Farmer 14 is with her crop productivities on the lower end of the spectrum of all the farmers (Table 11 and Table 18). Her total labour input for her farm is average although it misses one actual pair familiar hands. In Figure 16 it can be noticed that she is not capable of cultivating all her land, due to a lack of labour and an inability to hire additional labour. She is not able to hire any more labour due to the high costs. Her farm size is above the average with 1.4 ha. Hence farmer 14 is food insufficient not because of her small acreage but rather because her crops did not produce enough (Figure 14). Figure 15 shows that she would also remain food insecure however this figure takes only her farm production and income into account. This farmer is for 20% dependent for her income on the farm thus she might be more food secure than is actually shown. For her the increase of productivity of a few crops could make her less dependent on food from the market. When the productivity of maize and cassava increases acreage for those crops can be reduced in favour of banana. With the banana more money can be earned to reduce the losses she makes because of feeding her children (Figure 13).

Farmer 21 seems to have a hard time earning enough money of the farm (Figure 12). Farmer 21 has however a household of 17 persons which need to be fed. It is this amount of mouths that make it hard to make the farm profitable. The constraints of being able to feed all the people in the household in both scenarios of the constrained and free make it difficult to be self-sufficient. Figure 14 and Figure 15 however do show that farmer 21 becomes food self-sufficient and secure. This is purely based on the amount of calories that the household is able to produce which is mostly though banana and cassava, on which however the family cannot live alone. The productivity of this farm is high considering the spectrum of Table 11. For this farmer that is dependent for 40% of the total income on the farms income it is a better solution to focus on the off farm activities and see the half hectare as a big garden.

Farmer 24 has a similar amount of acreage (1.2 ha) as farmer 14 and has currently the highest food security ratio and the highest income. As can be seen in Figure 13 not much additional income is realized through the simulation of the constrained and free scenarios. The constrained scenario can add more calories to make the farm more FSS and provide some additional for FS but is it really necessary, once above the 1 ratio the rest is over production (Figure 14 and Figure 15). The question is; is it desirable for this farmer to improve his FSS and FS. He is clearly on the level were food crops cannot add much for FFS or FS. He is one of the few farmers that can hire labour and use it to increase his production (Table 13). Through his relatively high crop productivity he is able to stay on this level. Because all his crops have a relatively high productivity, productivity increases can alter some of his land allocations. If for instance coffee productivity increases he should allocate more land to coffee and maize and less to banana. Similarly for increases in the productivity of banana, coffee should be reduced and cassava should be increased. The dynamics between maize and cassava are such that if the productivity of maize increases more land should be allocated to cassava instead to maize, and not vice versa, because cassava produces much more and therefore can increase the income more. However farmer 24 is only for half of his income dependent on the farm thus choices on what to focus could assist in which crops to cultivate. If more time needs to be freed then labour extensive crops should be the focus. Contrary to that he could focus on crops which have a higher profitability but might need some additional labour input.

Another farmer that depends on farm products for a majority of their income is farmer 31 (Table 9). Although he farms only one tenth of the acreage that farmer 3 is farming he can still increase his income (Figure 13). No large changes in the allocation of land are proposed except that he does not have to cultivate any maize for the constrained scenario. He is also one the few farmers that, like farmer 3, is able to maintain acreage for others (Figure 16). In his case this is the cultivation of tomatoes, which is profitable enough to compete with the other crops. The amount of labour that he invests and its subsequent yields are clearly adequate enough to enable him to continue cultivating tomatoes in the constrained scenario. He can also cultivate tomatoes all year round, which explains his high yields. For the free scenario his farms is completely used for the cultivation of banana, simply because it is the most profitable crop, more so then tomatoes.

For farmer 43 who has 1.8 hectare and was food secure and is able to improve that with the proposed scenarios has many possibilities. Since the farm provides only 20% of her total income the questions is on what to focus. The advice from the model is to reduce the amount of land under coffee and stop with cultivating maize (Figure 16). Both crops are labour intensive crops and as such she can reduce the need for tending to those crops and be able to have a more constant income with banana. This makes it possible for her to focus more on her off-farm activities which provide 80% of her income.

6. Discussion

6.1. The study's major findings

The results show that considering the research question, solutions vary per farmer. The research question was: How can the farm households improve their current resource allocation, such that the farm households are food secure and at the same time achieve their maximum possible income from agricultural production? Through the allocation of land to various crops farmers can reduce the amount of labour necessary on the farm in both scenarios, increase in most cases their income in the free scenario and become food secure in both scenarios. As has been indicated in the results, not all farmers increase their income through the constrained and free scenarios. The food security constraint works irrespective of a positive income. Hence the farmers are food secure but are so because of food bought of the market. However for most farmers the land allocations which were optimized in the constrained and in the free scenario result in food secure and even self-sufficient farmers. The marketing of overproduction improves the situation for the farmers in terms of food security.

To answer the first sub research question: Most farmers were food secure, and those that were not can become food secure, although for some it costs money which has to either come from a higher crop production or from off-farm labour. In the current situation six farmers were not food secure, which was reduced to two in the constrained scenario based on the amount of calories that the household produced. The results indicated that land size is not necessarily a factor which makes a farmer food secure or insecure.

Considering the most economical simulation, which was the free scenario, the conclusion is that growing banana is the most profitable. However from the crops that the farmers can cultivate crops like coffee, beans and cassava provide benefits too. In the constrained scenario annual crops had to be cultivated and there the model allocates most of the land to beans and cassava. These two crops with coffee and banana have either a high whole sale price, high crop productivity or a low labour demand. Banana trumps at all three of those factors. Coffee has a high price, cassava has a high crop productivity and a low labour demand and beans have a high whole sale price. So considering price fluctuations, the diverse option would be to grow these four crops while the economic option would be to allocate land to banana and cassava. What should be taken into account is that banana, with cassava, are the crops that can be harvested any time of the year. This provides a constant cash flow, whereas beans and coffee provide a seasonal cash boom but a more diversified income.

6.2. Interpretation of the findings

As an ex-ante study on what kind of resource allocation would farmers benefit most, this study shows promising possibilities with regard to the allocation of land to the various crops which farmers can grow. The unique aspect of this thesis is that for each individual farmer two land allocation scenarios, constrained and free, were calculated such that the household could be food secure while maximizing their income. The possibility to increase their income further could also be achieved through the increase of land size (Table 14). However due to the land pressure that the farmers are experiencing it is impossible to increase their farm size to cultivate more land (Jassogne et al., 2014, 2013; Nkonya et al., 2004; Pender et al., 2004). Therefore it is important for the farmers that are for less than 50% dependent on their farm income what they want with their farm. For these farmers it is important to investigate if it is possible to become food secure and improve their income through off-farm income on the small farm acreages that they have.

Crop productivity

The reason why the very small farmers can still become food secure based on farm production is through their high crop productivities. However the chance that the productivities of these very small farmers will be reproducible on bigger scale is small since it is not profitable for the farmer to continue with the same high labour input (Harris and Orr, 2014; Rao and Chotigeat, 1981). Although the figures that the farmers recorded are not totally accurate they are farm specific values. The drop in the amount of farm labour that is required in the free scenario is explained through the low labour input values banana and cassava have compared to the other crops (Table 11 and Figure 18). Hence as the land allocated to banana and cassava increases the labour time decreases due to the low labour input need of those crops. Therefore the outcomes indicate that more of the land that farmers cultivate should be covered by banana and cassava but not that land should be directly cleared.

What needs to be kept in mind is that these farmers intercrop. Through quantifying the percentages of land that is allocated to each crop during the farmer meetings the difficulty of measuring "plots" was evaded. These farmers have no plots with crops but rather highly combined agroforestry gardens. In these systems the interactions between the crops are hard to quantify for banana and coffee it has been attempted although the yields are much lower compared to this study (van Asten et al., 2011). So the outcomes of the model on the land allocation should be read as a change in the ratio of the crops. However plant density starts to affect these outcomes too and the time that certain crops take before they yield.

Profitability

In terms of capital, banana and cassava are high productive crops with high yields and although the prices are not high, they are the most profitable (Table 3 and Table 11). What the farmers earn from the crops depends on how much of the produce is eaten by the household and the need of crop inputs and hired labour. The land allocation changes that are proposed to the farmers in this thesis are mainly driven by the profitability of bananas (Figure 8 and Figure 16). In the free scenario it is banana that is calculated to provide the highest income and increase food security for most farmers (Figure 15 and Figure 17). Even in the constrained scenario the model tended to allocate as much land as possible to banana (Figure 16 and Figure 17). What the farmers in this study are achieving with banana remains possible even when the profitability of banana is on the level of what literature indicates (FAO, 2015; Nabbumba and Bahiigwa, 2003; Nyombi, 2010; van Asten et al., 2012, 2011; Wairegi and van Asten, 2010). Only cassava has a crop productivity approaching that of banana, however cassava prices are half that of banana prices (Farmgain Africa Limited, 2014; Fermont et al., 2009; FIT Uganda ltd and Agricultrual Sector Program Support, n.d.). The constrained scenario reflects the profitability of cassava as it is the second crop to cultivate in that scenario. As stated before the farmers eat cassava only in dire moments, this does not impede the possibility of selling it on the market.

Validity of the model

Since the number of farmers in this research was rather limited, extrapolation to bigger regions is not realistic. The results are farm specific and cannot be applied to another farm or farms. The model can be applied on other farms given proper input data. The models predictability decreases from FSS to

FS and should not be used for predicting income. The decreasing strength of the relations is due to the uncertainty of commodity prices that the farmers receive for their products. Hence if the prices could be better specified, and a larger group of farmers could be investigated, the outcomes could be validated. Additionally to enhance the strength for the predictability of income it would help if exactly is known how much farmers sell and not harvest in this research the harvested amounts were known but not the weights of the sold products. In the model calculation the whole harvest is sold whereas farmers do also eat parts of their produce.

From the sensitivity analysis land size, labour, crop productivity and commodity prices have a high impact on the income of the households (Table 14). Land size has an obvious relation, in the sense that more land under cultivation leads to more products if total labour would allow for it (Dogliotti et al., 2004). An increase in labour availability or a higher labour efficiency would give farmers more cropping possibilities. The other crop category contained annual crops and fruits. This category could be split and used to focus extensively on the annual crops that are grown on each farm. This could help on focussing on very labour intensive crops which were lumped together now in the other category to explore other cropping possibilities with different labour requirements (Dogliotti et al., 2005, 2003). The effects of crop productivity on the results have been discussed above. However not all farmers are on the same productivity level and some could benefit from an increase in productivity. An increase in crop productivity could be achieved by increased use of fertilizer and or improved crop management (Tittonell and Giller, 2013). Although an increase in input use could possibly help farmers. In Table 9 the column farm inputs shows that some farmers spend money on inputs however not all farmers made clear which, how much and on which crops. In the model the effects of price increases or decrease are drastic for some crops. These effects are particularly prominent for crops with high yields and the cash crop coffee, in comparison to crops that do not produce so much. This result is similar to what has been found in Kenya where cash crops (dessert banana) become the preference when land pressure increases (Herrero et al., 2014).

Usability of the solutions

Not all farmers benefit from the crop allocations proposed by the scenarios run through the model. The farmers that go into the red and the farmers that are actually not that dependent on the income of their farm, rather keeping it as an enlarged vegetable garden, might prefer to look at other possibilities (Table 9 and Figure 13). An option would be then to focus on off-farm labour as a main source of income and leave farming to those that can increase their farm production as happened in Kenya (Hengsdijk et al., 2014; Herrero et al., 2014).

This study was an ex-ante investigation of which land allocation could make farmers more food secure and economically profitable. As expected from a crop allocation study the outcomes tend to focus on increasing the acreage of the most profitable crop. Because the model focusses on the most productive and profitable crop the prioritized crop is banana. Most farmers were food secure from the onset therefore a more participatory approach could have increased the applicability of the results. This is especially relevant in the cases where farmers were food secure and off-farm labour did not account for much in the household's income (Table 9, Figure 13 and Figure 15). This could have been anticipated better through the use of participatory research methods (Bentley, 1994; Dogliotti et al., 2004; Klapwijk et al., 2014; Voinov and Bousquet, 2010). Through the participatory process the dynamic knowledge of the farmers could have been used much more. The farmers know their situation the best and hence are better able to judge what might work and what not (van Asten et al., 2008). In this light an alternative option in addition to the constrained and the free scenario could have been the option that explores the land allocation when the maximum income is decreased by 1%. This strategy could offer an additional set of options of which the farmers could have chosen their preferred allocation (Abdulkadri and Ajibefun, 1998; Makowski et al., 2000).

6.3. Suggestions for further research

This research has been on data that was collected by the farmers on a daily basis. For further research seasonal interactions could be analysed. The interactions of annual crops on the income and food security in regards to two cropping seasons, and possible cultivation strategies might be considered. This could give more insight into seasonal food insecurity and possible methods to counter it. The other crop category contained annual crops and fruits. This category could be split and used to focus extensively on the annual crops that are grown on each farm. This is especially crucial when considering farmers such as farmer 31, who is in effect more a tomato farmer than a banana or coffee grower.

Crop productivity had a major effect on the outcomes of the model. Although there is a high variation between the farmers in their crops productivities some farmers have extremely high crop productivities. Further research on these high productive farms could shine light on its possibility. Crop yields and acreage have to be assessed more accurately. All farms in this study are agroforestry systems in which the cropping density is high, although not necessary with the same crop. This would resolve the problem with the potentially inaccurate estimations by the farmers, which might be accurate in quantity but not spatially. In addition fertilizer, improved varieties and pest management tools could enhance the crop productivity for the low productive farms such that farmers might be capable of increasing their yields. In the light of the further intensification of smallholder farmers as promoted by the FAO, it might be right to investigate how crop productivity of small holder intercropped agroforestry systems fits in mono crop models (Carletto et al., 2013a; Dixon et al., 2001; Rao and Chotigeat, 1981; Thompson et al., 1996; Tittonell and Giller, 2013; van Wijk et al., 2009).

Additional validation of the model by the farmers through participatory modelling and improving scenarios to analyse dynamics of their farm is recommended (Bentley, 1994; Dogliotti et al., 2004; Klapwijk et al., 2014; Voinov and Bousquet, 2010). The changes of commodity prices, labour prices, land prices and input prices can especially give insight to the farmers (Campenhout et al., 2013).

7. Conclusion

From this research the lessons can be learned that using logbooks without proper feedback mechanisms and checks creates data that is not reliable. Through the continuous build-up of little errors in measurements and registration especially crop productivities are acquired that are unrealistic. To counter act this clear and regular communication with the farmers on their activities is necessary. Although the initial data is not reliable it has been used for modelling these 26 farms. Through using an linear programming model with three different scenarios, specific land allocation options for each farm have been explored that allow them to consider re-allocation of their resource investments such that it enhances their income, reduces their labour input and provides enough to be food secure. The optimal land allocation differs among farmers depending on their current farm performance. These results have to carefully communicated to the farmers since the data on which it is based is flawed. It is here were the participatory part of the research should have come in. Due to time constraints this has not been possible but remains important for reaching the farmers and providing them with feedback on their activities and possible cropping alternatives.

The resource allocation of some of the farmers can be improved, such that farmers will need less time to care for their crops, earn more money from their crops and become more food secure. The major driver behind these improvements is banana, although for each farmer the model focusses on the most productive crop which is very farm specific. The results are an ex-ante study on possibilities for these farmers and as such should be carefully communicated. Because the data from the logbooks has been recorded by the farmers themselves the reliability is in the case of crop productivities and labour input doubtful. It is this case that a better measuring of the weight units, time and land could have increased the accuracy. An additional case should be made for the very small scale on which these farmers work and that extrapolating their activities to hectare scale should be done with caution. If the uncertainties and results are communicated carefully participatory solutions can be implemented to aid the households.

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10. Appendix

Appendix A. An example of the logbook of farmer 24.

Appendix B. Tables with household data.

Appendix C. The crops productivity and labour input.

Appendix D. Income table of all the farmers from the scenarios.

Appendix E. The script of the base scenario, three tables containing the information for the objective function and the constraints of all three scenarios and a table with right hand side values.

Appendix A. A logbook example

Here screenshots of an example of a logbook of farmer 24 are shown. The first shows the activity log, the second shows the harvest log which is followed by the investment and expenditure log and finally followed by the income log. The codes are explained in the last table.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK
1	Region	HHCode	Date.activity	Month	Day	PlotNR.activity	Activity.Name	Product.activity	Tool.activity	Input.Use	Input.Type	Input.Name	Input.Q.Used	Input.Q.Saved	Input.Unit	Input.Costs	L.M.Own.Nr	L.M.Own.Hrs	TOTAL.M.Fam	L.F.Own.Nr	L.F.Own.Hrs	TOTAL.F.Fam	L.M.Hire.Nr	L.M.Hire.Hrs	TOTAL.M.Hire	L.F.Hire.Nr	L.F.Hire.Hrs	TOTAL.F.Hire	L.Child.Nr	L.Child.Hrs	Total.Child	L.Costs	TOTAL.Labour	TOTAL.Hire	TOTAL.Fam	Total.M.labour	Total.F.Labour
2	Luwero	24	2013	Aug	1	A	7	1	9	666	666	666	666	666	666	666	1	1.5	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	1.5	0	1.5	1.5	0
3	Luwero	24	2013	Aug	2	B	1	2	1	666	666	666	666	666	666	666	1	1.5	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	1.5	0	1.5	1.5	0
4	Luwero	24	2013	Aug	2	B	7	1	9	666	666	666	666	666	666	666	0	0	0	1	2	2	0	0	0	0	0	0	0	0	0	0	2	0	2	0	2
5	Luwero	24	2013	Aug	3	B	7	1	9	666	666	666	666	666	666	666	1	1.5	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	1.5	0	1.5	1.5	0
6	Luwero	24	2013	Aug	4	A	3	1	5	666	666	666	666	666	666	666	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	2	0
7	Luwero	24	2013	Aug	6	B	15	4	1	666	666	666	666	666	666	666	1	2.5	2.5	1	2.5	2.5	0	0	0	0	0	0	2	2.5	2.5	0	7.5	0	7.5	2.5	2.5
8	Luwero	24	2013	Aug	7	A	3	1	5	666	666	666	666	666	666	666	1	1	1	0	0	0	1	2	2	0	0	0	0	0	0	10000	3	2	1	3	0
9	Luwero	24	2013	Aug	8	B	15	4	1	666	666	666	666	666	666	666	1	2.5	2.5	1	2.5	2.5	0	0	0	0	0	0	2	2.5	2.5	0	7.5	0	7.5	2.5	2.5
10	Luwero	24	2013	Aug	9	B	15	2	1	666	666	666	666	666	666	666	1	2	2	1	2	2	0	0	0	0	0	0	2	2	2	0	6	0	6	2	2
11	Luwero	24	2013	Aug	11	B	15	5	1	666	666	666	666	666	666	666	1	1.5	1.5	1	1.5	1.5	0	0	0	0	0	0	0	0	0	0	3	0	3	1.5	1.5
12	Luwero	24	2013	Aug	12	B	15	4	1	666	666	666	666	666	666	666	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	2	0	2	1	1
13	Luwero	24	2013	Aug	13	B	1	2	1	666	666	666	666	666	666	666	1	2	2	1	2	2	0	0	0	0	0	0	2	2	2	0	6	0	6	2	2
14	Luwero	24	2013	Aug	14	A	4	2	2	666	666	666	666	666	666	666	0	0	0	1	1.5	1.5	0	0	0	0	0	0	1	1.5	0.75	0	2.25	0	2.25	0	1.5
15	Luwero	24	2013	Aug	15	A	4	2	2	666	666	666	666	666	666	666	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1
16	Luwero	24	2013	Aug	16	A	30	999	1	666	666	666	666	666	666	666	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	2	0
17	Luwero	24	2013	Aug	17	B	1	2	1	666	666	666	666	666	666	666	1	2	2	1	2	2	0	0	0	0	0	0	2	2	2	0	6	0	6	2	2
18	Luwero	24	2013	Aug	17	B	1	1	1	666	666	666	666	666	666	666	0	0	0	0	0	0	1	3	3	0	0	0	0	0	0	8000	3	3	0	3	0
19	Luwero	24	2013	Aug	18	B	3	1	5	666	666	666	666	666	666	666	0	0	0	0	0	0	1	1.5	1.5	0	0	0	0	0	0	5500	1.5	1.5	0	1.5	0
20	Luwero	24	2013	Aug	18	B	3	1	5	666	666	666	666	666	666	666	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	0	2	0	2	0	0
21	Luwero	24	2013	Aug	20	B	1	999	1	666	666	666	666	666	666	666	1	2	2	0	0	0	0	0	0	0	0	0	2	2	2	0	4	0	4	2	0
22	Luwero	24	2013	Aug	20	B	7	5	1	666	666	666	666	666	666	666	0	0	0	1	0.33	0.33	0	0	0	0	0	0	0	0	0	0	0.33	0	0.33	0	0.33
23	Luwero	24	2013	Aug	24	B	7	1	9	666	666	666	666	666	666	666	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0
24	Luwero	24	2013	Aug	24	B	1	4	1	666	666	666	666	666	666	666	0	0	0	1	2	2	0	0	0	0	0	0	2	2	2	0	4	0	4	0	2
25	Luwero	24	2013	Aug	26	B	15	27	1	666	666	666	666	666	666	666	1	4	4	1	4	4	0	0	0	0	0	0	2	4	4	0	12	0	12	4	4
26	Luwero	24	2013	Aug	26	A	12	10	9	666	666	666	666	666	666	666	1	0.16	0.16	0	0	0	0	0	0	0	0	0	0	0	0	0	0.16	0	0.16	0.16	0
27	Luwero	24	2013	Aug	26	A	6	10	4	7	7	sese	25	225	ml	12000	1	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0.5	0.5	0
28	Luwero	24	2013	Aug	27	A	3	2	5	666	666	666	666	666	666	666	0	0	0	0	0	0	0	0	0	0	0	0	2	1.5	1.5	0	1.5	0	1.5	0	0
29	Luwero	24	2013	Aug	28	B	2	4	1	666	666	666	666	666	666	666	0	0	0	1	2	2	0	0	0	0	0	0	2	2	2	0	4	0	4	0	2
30	Luwero	24	2013	Aug	28	B	5	1	2	666	666	666	666	666	666	666	1	1.5	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	1.5	0	1.5	1.5	0
31	Luwero	24	2013	Aug	29	B	7	1	9	666	666	666	666	666	666	666	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0
32	Luwero	24	2013	Aug	29	B	2	4	1	666	666	666	666	666	666	666	0	0	0	0	0	0	0	0	0	0	0	0	2	1.5	1.5	0	1.5	0	1.5	0	0
33	Luwero	24	2013	Aug	30	A	3	2	5	666	666	666	666	666	666	666	0	0	0	1	1.5	1.5	0	0	0	0	0	0	2	2	2	0	3.5	0	3.5	0	1.5
34	Luwero	24	2013	Aug	30	B	7	1	9	666	666	666	666	666	666	666	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	2	0
35	Luwero	24	2013	Aug	30	B	19	10	2	666	666	666	666	666	666	666	1	0.33	0.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0.33	0	0.33	0.33	0
36	Luwero	24	2013	Aug	30	B	2	4	1	666	666	666	666	666	666	666	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1
37	Luwero	24	2013	Sep	1	A	3	2	5	666	666	666	666	666	666	666	1	2	2	0	0	0	0	0	0	0	0	0	2	1.5	1.5	0	3.5	0	3.5	2	0
38	Luwero	24	2013	Sep	1	B	19	10	2	666	666	666	666	666	666	666	1	2.5	2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	2.5	0	2.5	2.5	0

Blad1 | Table A Activity | Table B Harvest | Table C Investment | Table D Income

The harvest log

	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW
1	Date.harvest	Month	Day	PlotNR.harvest	Product.harvest	Quantity.harvest	Unit.harvest	Q.Consumed	Q.Given	Q.Saved	Q.Sold	Income.harvest	Kg.COFFEE	Nr.Banana	Kg.Maize	Kg.Beans	Kg.Cassava	Kg.SweetPotato	Kg.Irish	Kg.Cabbage	Kg.Tomato	Kg.HotPepper	Kg.tobacco	Nr.trees	Nr.Avocado	Nr.Pawpaw	Nr.Mango	Nr.Jackfruit	Nr.pumpkin	Nr.Sugarcane	Nr.Watermelon	Nr.Pineapple	Kg.Passion	Kg.Yams	Kg.G-nuts	Kg.greens	Kg.Eggplant	Kg.Ntula	Kg.Soybeans	TOTAL.KG	Total.Kg.Consumed	Total.Kg.Given	Total.Kg.Saved	Total.Kg.Sold	%Sold	old	Diff
2	2013	Aug	20	A	5	2	P	2	0	0	0	0	FALSE	FALSE	FALSE	FALSE	13	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	13	13	0	0	0	0	13	0
3	2013	Aug	21	A	2	1	BB	1	0	0	0	0	FALSE	17	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	17	17	0	0	0	0	17	0
4	2013	Aug	22	G	6	1	Bs	0.5	0	0.5	0	0	FALSE	FALSE	FALSE	FALSE	FALSE	20	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	20	10	0	10	0	0	20	0
5	2013	Aug	23	G	2	1	BB	1	0	0	0	0	FALSE	17	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	17	17	0	0	0	0	17	0
6	2013	Aug	24	A	2	1	BB	1	0	0	0	0	FALSE	17	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	17	17	0	0	0	0	17	0
7	2013	Aug	26	A	5	1	Bs	0.5	0.5	0	0	0	FALSE	FALSE	FALSE	FALSE	20	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	20	10	10	0	0	0	20	0
8	2013	Aug	27	A	17	1	Bs	0.5	0.5	0	0	0	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	25	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	25	12.5	12.5	0	0	0	25	0
9	2013	Aug	27	B	2	3	BB	0	0	0	3	32000	FALSE	51	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	51	0	0	0	51	100	51	0
10	2013	Aug	28	B	6	1	Bs	0.5	0	0.5	0	0	FALSE	FALSE	FALSE	FALSE	FALSE	20	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	20	10	0	10	0	0	20	0
11	2013	Aug	29	B	2	1	BB	0	0	1	0	0	FALSE	17	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	17	0	0	17	0	0	17	0
12	2013	Aug	29	A	2	3	BB	0	0	0	3	30000	FALSE	51	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	51	0	0	0	51	100	51	0
13	2013	Aug	29	B	1	2	T	0	0	2	0	0	30.6	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	30.6	0	0	30.6	0	0	31	0
14	2013	Aug	30	A	2	2	BB	1	0	1	0	0	FALSE	34	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	34	17	0	17	0	0	34	0
15	2013	Aug	30	B	1	2	T	0	0	2	0	0	30.6	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	30.6	0	0	30.6	0	0	31	0
16	2013	Aug	30	A	2	2	BB	1	1	0	0	0	FALSE	34	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	34	17	17	0	0	0	34	0
17	2013	Aug	30	B	17	1	Bs	0.5	0.5	0	0	0	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	25	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	25	12.5	12.5	0	0	0	25	0
18	2013	Sep	4	A	5	1	P	1	0	0	0	0	FALSE	FALSE	FALSE	FALSE	6.5	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	6.5	6.5	0	0	0	0	6.5	0
19	2013	Sep	6	B	6	1	Bs	0.5	0	0.5	0	0	FALSE	FALSE	FALSE	FALSE	FALSE	20	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	20	10	0	10	0	0	20	0
20	2013	Sep	6	A	2	2	BB	0	2	0	0	0	FALSE	34	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	34	0	34	0	0	0	34	0
21	2013	Sep	6	B	17	0.5	Bs	0.5	0	0	0	0	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	12.5	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	12.5	12.5	0	0	0	0	13	0
22	2013	Sep	7	A	1	3	T	0	0	3	0	0	45.9	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	45.9	0	0	45.9	0	0	46	0
23	2013	Sep	7	B	2	1	BB	1	0	0	0	0	FALSE	17	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	17	17	0	0	0	0	17	0
24	2013	Sep	7	B	5	1	Bs	0	0	0	1	25000	FALSE	FALSE	FALSE	FALSE	100	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	100	0	0	0	100	100	100	0
25	2013	Sep	8	A	2	4	BB	1	1	0	2	20000	FALSE	68	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	68	17	17	0	34	50	68	0
26	2013	Sep	8	B	6	1.5	Bs	0.5	1	0	0	0	FALSE	FALSE	FALSE	FALSE	FALSE	30	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	30	10	20	0	0	0	30	0
27	2013	Sep	8	B	1	4	T	0	0	4	0	0	61.2	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	61.2	0	0	61.2	0	0	61	0
28	2013	Sep	9	B	5	1	P	1	0	0	0	0	FALSE	FALSE	FALSE	FALSE	6.5	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	6.5	6.5	0	0	0	0	6.5	0
29	2013	Sep	9	A	2	1	BB	1	0	0	0	0	FALSE	17	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	17	17	0	0	0	0	17	0
30	2013	Sep	9	B	31	1	F	1	0	0	0	0	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	1	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	1	1	0	0	0	0	1	0
31	2013	Sep	9	A	18	3	F	1	0	2	0	0	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	3	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	3	1	0	2	0	0	3	0
32	2013	Sep	9	A	1	2	T	0	0	2	0	0	30.6	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	30.6	0	0	30.6	0	0	31	0
33	2013	Sep	10	B	2	2	BB	1	0	1	0	0	FALSE	34	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	34	17	0	17	0	0	34	0
34	2013	Sep	11	B	5	1	P	1	0	0	0	0	FALSE	FALSE	FALSE	FALSE	6.5	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	6.5	6.5	0	0	0	0	6.5	0
35	2013	Sep	11	B	1	1	T	0	0	1	0	0	15.3	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	15.3	0	0	15.3	0	0	15	0
36	2013	Sep	12	B	1	1.5	T	0	0	1.5	0	0	22.95	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	23	0	0	22.95	0	0	23	0
37	2013	Sep	12	B	2	2	BB	0	0	0	2	20000	FALSE	34	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	34	0	0	0	34	100	34	0
38	2013	Sep	12	A	2	2	BB	1	0	1	0	0	FALSE	34	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	34	17	0	17	0	0	34	0
39	2013	Sep	12	A	1	1	Bs	0	0	1	0	0	15.8	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	15.8	0	0	15.8	0	0	16	0
40	2013	Sep	13	B	6	1	Bs	1	0	0	0	0	FALSE	FALSE	FALSE	FALSE	FALSE	20	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	20	20	0	0	0	0	20	0
41	2013	Sep	14	B	2	2	BB	1	1	0	0	0	FALSE	34	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	34	17	17	0	0	0	34	0
42	2013	Sep	14	B	1	1	T	0	0	1	0	0	15.3	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	15.3	0	0	15.3	0	0	15	0
43	2013	Sep	15	B	5	1	P	1	0	0	0	0	FALSE	FALSE	FALSE	FALSE	6.5	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	6.5	6.5	0	0	0	0	6.5	0
44	2013	Sep	15	B	2	1	BB	1	0	0	0	0	FALSE	17	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	17	17	0	0	0	0	17	0
45	2013	Sep	16	B	5	1	P	1	0	0	0	0	FALSE	FALSE	FALSE	FALSE	6.5	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	6.5	6.5	0	0	0	0	6.5	0
46	2013	Sep	17	B	2	1	BB	1	0	0	0	0	FALSE	17	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	17	17	0	0	0	0	17	0
47	2013	Sep	17	B	6	1	Bs	0.5	0	0.5	0	0	FALSE	FALSE	FALSE	FALSE	FALSE	20	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	20	10	0	10	0	0	20	0
48	2013	Sep	17	B	1	2	T	0	0	2	0	0	30.6	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	30.6	0	0	30.6	0	0	31	0
49	2013	Oct	11	B	1	3	T	0	0	3	0	0	45.9	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	45.9	0	0	45.9	0	0	46	0
50	2013	Oct	11	A	1	2	T	0	0	2	0	0	30.6	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	30.6	0	0	30.6	0	0	31	0
51	2013	Oct	11	A	6	1	Bs	1	0	0	0	0	FALSE	FALSE	FALSE	FALSE	FALSE	20	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	20	20	0	0	0	0	20	0
52	2013	Oct	11	A	2	3	BB	0	0	0	3	30000	FALSE	51	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	51	0	0	0	51	100	51	0

Blad1 | Table A Activity | Table B Harvest | Table C Investment | Table D Income

The investment and expenditure log

	Region	HHCode	Date.invest/expen	Month	Day	Investment/Expenditure.type	Invest/Expen.name	Invest/Expen.quantity	Invest/Expen.unit	Invest/Expen.costs	Comments.invest/expen
2	Luwero	24	2013	Aug	7	16	labour	1	it	10,000	Paid labour
3	Luwero	24	2013	Aug	7	7	paraffin	1	L	4,100	bought paraffin
4	Luwero	24	2013	Aug	10	10	medicine	1	it	12,000	bought medicine
5	Luwero	24	2013	Aug	11	5	transport	1	it	10,000	transport to kampala
6	Luwero	24	2013	Aug	15	6	sauce	1	it	9,000	bought sauce
7	Luwero	24	2013	Aug	17	16	labour	1	it	8,000	Paid labour
8	Luwero	24	2013	Aug	18	16	labour	1	it	5,500	Paid labour
9	Luwero	24	2013	Aug	20	7	bed sheets	1	it	23,000	bought bed sheets
10	Luwero	24	2013	Aug	22	7	paraffin	2	L	8,200	bought paraffin
11	Luwero	24	2013	Aug	23	12	repair	1	it	22,000	repaired moto cycle
12	Luwero	24	2013	Aug	23	13	air time	1	it	3,000	bought air time
13	Luwero	24	2013	Aug	24	7	money 4 home use	1	it	45,000	money for home use
14	Luwero	24	2013	Aug	25	3	iron sheets	1	it	50,000	bought iron sheets
15	Luwero	24	2013	Aug	25	1	g. nuts	5	kg	10,000	bought g. nuts 4 planting
16	Luwero	24	2013	Aug	27	11	school fees	1	it	35,000	paid school fees
17	Luwero	24	2013	Aug	27	7	money 4 home use	1	it	37,000	money for home use
18	Luwero	24	2013	Aug	27	5	petral	1	L	5,000	bought petral
19	Luwero	24	2013	Aug	28	5	petral	1	L	5,000	bought petral
20	Luwero	24	2013	Aug	28	13	air time	1	it	2,000	bought air time
21	Luwero	24	2013	Sep	1	7	money 4 home use	1	it	7,400	money for home use
22	Luwero	24	2013	Sep	2	16	labour	1	it	20,000	Paid labour
23	Luwero	24	2013	Sep	2	5	petral	1	L	5,000	bought petral
24	Luwero	24	2013	Sep	3	5	transport	1	it	10,000	transport to kampala
25	Luwero	24	2013	Sep	4	7	money 4 home use	1	it	7,000	money for home use
26	Luwero	24	2013	Sep	4	5	oil 4 motocycle	1	it	14,000	bought oil
27	Luwero	24	2013	Sep	5	6	maize flour	2	kg	4,000	bought maize flour
28	Luwero	24	2013	Sep	5	13	air time	1	it	2,000	bought air time
29	Luwero	24	2013	Sep	6	5	petral	1	L	5,000	bought petral
30	Luwero	24	2013	Sep	7	7	money 4 home use	1	it	7,000	money for home use
31	Luwero	24	2013	Sep	7	16	labour	1	it	12,000	Paid labour
32	Luwero	24	2013	Sep	7	12	repair	1	it	3,000	repaired moto cycle
33	Luwero	24	2013	Sep	7	14	savings	1	it	8,400	savings
34	Luwero	24	2013	Sep	8	10	medicine	1	it	600	bought medicine
35	Luwero	24	2013	Sep	8	8	plot	1	it	1,000,000	bought a plot
36	Luwero	24	2013	Sep	8	7	hoe	2	it	18,000	bought hoes
37	Luwero	24	2013	Sep	9	12	repair	1	it	2,000	repaired moto cycle
38	Luwero	24	2013	Sep	10	6	rice	2	kg	6,000	bought rice
39	Luwero	24	2013	Sep	10	16	labour	1	it	12,500	Paid labour

Blad1 | Table A Activity | Table B Harvest | **Table C Investment** | Table D Income

The income log

	A	B	C	D	E	F	G	H	I
1	**Region**	**HHCode**	**Date.income**	**Month**	**Day**	**Income.Source**	**Income.Quantity**	**Comments.income**	
2	Luwero	24	2013	Aug	4	8	40,000	sold coffee	
3	Luwero	24	2013	Aug	10	3	670,000	delt some thing	
4	Luwero	24	2013	Aug	14	8	30,000	sold cassava	
5	Luwero	24	2013	Aug	17	1	50,000	given by the mother	
6	Luwero	24	2013	Aug	17	3	15,000	got from motor cycle	
7	Luwero	24	2013	Aug	19	4	42,000	from town council	
8	Luwero	24	2013	Aug	22	9	30,000	allowance from the workshop	
9	Luwero	24	2013	Aug	22	3	10,000	got from moto cycle	
10	Luwero	24	2013	Aug	27	6	50,000	he was paid pack	
11	Luwero	24	2013	Aug	28	6	27,500	he was paid pack	
12	Luwero	24	2013	Aug	28	9	10,000	got from gender	
13	Luwero	24	2013	Aug	29	4	42,000	from town council	
14	Luwero	24	2013	Aug	30	3	8,000	got from motor cycle	
15	Luwero	24	2013	Aug	31	8	62,000	Collected from Table B	
16	Luwero	24	2013	Sep	26	8	78,500	sold coffee	
17	Luwero	24	2013	Sep	29	8	28,000	sold banana	
18	Luwero	24	2013	Sep	30	2	15,000	he was given	
19	Luwero	24	2013	Sep	30	8	65,000	Collected from Table B	
20	Luwero	24	2013	Oct	14	4	80,000	from town council	
21	Luwero	24	2013	Oct	15	6	100,000	he was paid pack	
22	Luwero	24	2013	Oct	15	2	10,000	he was given	
23	Luwero	24	2013	Oct	18	9	20,000	from work shop	
24	Luwero	24	2013	Oct	18	3	8,000	got from motor cycle	
25	Luwero	24	2013	Oct	19	8	180,000	sold coffee	
26	Luwero	24	2013	Oct	23	3	26,000	got from motor cycle	
27	Luwero	24	2013	Oct	23	8	10,000	sold banana	
28	Luwero	24	2013	Oct	24	2	5,000	he was given	
29	Luwero	24	2013	Oct	25	2	15,000	he was given	
30	Luwero	24	2013	Oct	26	8	19,000	sold banana	
31	Luwero	24	2013	Oct	27	8	22,000	sold banana	
32	Luwero	24	2013	Oct	29	8	175,000	sold coffee	
33	Luwero	24	2013	Oct	30	8	35,000	sold banana	
34	Luwero	24	2013	Oct	31	8	297,000	Collected from Table B	
35	Luwero	24	2013	Oct	31	8	20,000	sold banana	
36	Luwero	24	2013	Nov	30	8	140,000	sold coffee	
37	Luwero	24	2013	Nov	30	8	94,000	Collected from Table B	
38	Luwero	24	2013	Dec	1	6	4,000	he was paid pack	
39	Luwero	24	2013	Dec	3	3	5,000	got from motor cycle	

Blad1 | Table A Activity | Table B Harvest | Table C Investment | **Table D Income**

The explanations of the codes

Table A Activity

Activity.Name	Product.activity	Tool.activity	Input.Use	Input.Type	Input.Unit
1= digging	1= coffee	1= hoe	1= Chemical weeding	1= Herbicide	L = Liters
2= weeding	2= banana	2= panga	2= Organic fertilizing	2= Manure	Cl= Centi-Liters
3= slashing	3= maize	3= secateur	3= Chemical fertilizing	3= Artificial fertilizer	Ml= Milli-Liters
4= Prunning	4= beans	4= spraying pump	4= Organic plant protection	4= Organic pesticide	Kg = Kilogram
5= desuckering	5= casava	5= slasher	5= Chemical plant protection	5= Artificial pesticide	G = Gram
6= spraying	6= sweet potato	6= axe	6=Animal feed	6=Animal feed	Ba= Bags
7= harvesting	7= irish potato	7= knife	7=Acaricide	7=Acaricide	Bun= Bundle
8= fertilising	8= cabage	8= basin			BB= Banana Bunch
9= digging holes	9= tomato	9= bag			Bk= Bucket
10= processing	10= cows	10= rope			Bs= Basin
11= feeding animals	11= pigs	11= tin			WB= Wheelbarrow
12= tethering animals	12= goats	12= tarpaulin			MT= Medium Truck
13= spraying animals	13= chicken	13=fork			LT= Large Truck
14= drying	14= sheep	14=bucket			P= Plant
15= planting	15= fruit-trees	15= Polypots			T= Tin
16= thinning	16= trees	16=Wheel barrow			C=Cup
17=burning	23=eggs	17=Bicycle			Bx=Box
18= collecting grass	25=yams	18=rake			pl=plate
19= fodder collection	26=hot pepper	19=brush			Jc=Jerry can
20= gap filling	27=G.nuts	20=thorns			
21=off farm activity	28=Rice	21= motorcycle			
22=potting	29=soyabeans	22=stick			
23=ferrying	30=-Piglets	23=watering can			
24= mulching	31=Jackfruit	24=baskets			
25=fencing	32=Chicken	25=plate			
26=cutting trees	33=Vanilla	26=nail			
27=Shelter construction	34=Tobacco	27=jerrycan			
28=Pollinating	35=pumpkin	28=cup			
29=irrigating	36=ntula	29=spade			
30=digging water trenches	37=greens	30=hammer			
31=Milking	38=sugarcane	31=box			
32=cleaning animal house	39=watermelon	32= machine			
33=up rooting old plants	40=egg plant	33=spear			
34=guarding maize	41=green paper				
	42=oranges				

Table B Harvest

Product.harvest	Unit.harvest
1= coffee	L = Liters
2= banana	Cl= Centi-Liters
3= maize	Ml= Milli-Liters
4= beans	Kg = Kilogram
5= cassava	G = Gram
6= sweet potato	Ba= Bags
7= irish potato	Bun= Bundle
8= cabage	BB= Banana Bunch
9= tomato	Bk= Bucket
16=Trees	Bs= Basin
17 = avocado	WB= Wheelbarrow
18= pawpaw	MT= Medium Truck
19= mango	LT= Large Truck
20= pineapple	P= Plant
21= passionfruit	T= Tin
22= milk	C=Cup
23= eggs	Bx=Box
24= meat	Cob=MaizeCob
25=yams	A=Animal
26=hot pepper	F=Fruit
27=G.nuts	Tu=Tubers
28=Rice	Bas=Baskets
29=Soyabeans	TR= Tray
30=Piglets	
31=Jackfruit	
32=Chicken	
33=Vanilla	
34=Tobacco	
35=Pumpkin	
36=Ntula	
37=Greens	
38=Sugarcane	
39=Watermelon	
40=egg plant	
41=green paper	
42=oranges	

Table C Investments

Investment/Expenditure.type	Invest/Expen.unit
1=Farm inputs	L = Liters
2=Tools	Cl= Centi-Liters
3=Building	Ml= Milli-Liters
4=Equipment	Kg = Kilogram
5=Transport	G = Gram
6=Food	Ba= Bags
7=House-items	Bun= Bundle
8=Assets	BB= Banana Bunch
9=Animal Health	Bk= Bucket
10=People Health	Bs= Basin
11=School fees	WB= Wheelbarrow
12=Other	MT= Medium Truck
13=Airtime	LT= Large Truck
14=Debts, savings and loans	P= Plant
15=Gifts/Offerings	T= Tin
16=Labour	Tr= Trip
17=business investments	It= Item
	Bar=Bar
	Fun=Funnel
	Cu =Cup
	Bi=Bicycle

Table D Income

Income.Source
1= Remittances
2= Gifts
3= Business
4= Salary
5= Casual wages
6= Village savings (loans)
7= Bank loans
8= Farm Produce
9=Others
10=Animal sales

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Appendix B. Household data

Table 16. The current land allocation of the farmers over the various crops according to the farmers.

	Area (ha)						
Household number	Farm size	Coffee	Banana	Maize	Beans	Cassava	Other
1	2.30	0.58	0.69	0.46	0.23	0.23	0.12
2	0.84	0.25	0.13	0.08	0.21	0.13	0.04
3	4.02	0.80	0.20	1.41	1.01	0.20	0.40
5	1.52	0.53	0.30	0.15	0.23	0.23	0.08
7	0.64	0.19	0.06	0.22	0.06	0.03	0.06
8	0.51	0.08	0.03	0.13	0.10	0.10	0.08
10	4.08	0.82	0.41	1.02	0.61	0.41	0.82
11	0.65	0.16	0.03	0.23	0.13	0.06	0.03
12	0.60	0.21	0.12	0.09	0.03	0.09	0.06
14	1.47	0.29	0.44	0.22	0.22	0.15	0.15
15	0.20	0.09	0.02	0.01	0.02	0.03	0.03
16	0.68	0.21	0.03	0.14	0.14	0.07	0.10
21	0.54	0.16	0.13	0.03	0.08	0.08	0.05
24	1.27	0.51	0.32	0.25	0.06	0.06	0.06
31	0.45	0.11	0.04	0.16	0.04	0.02	0.07
33	0.53	0.13	0.11	0.11	0.08	0.05	0.05
37	0.34	0.13	0.05	0.03	0.08	0.02	0.02
39	1.57	0.55	0.31	0.08	0.31	0.24	0.08
40	0.87	0.48	0.09	0.09	0.13	0.04	0.04
41	0.94	0.33	0.14	0.14	0.09	0.09	0.14
43	1.78	0.71	0.36	0.36	0.09	0.18	0.09
45	0.20	0.05	0.03	0.05	0.03	0.02	0.02
48	0.22	0.09	0.04	0.03	0.02	0.02	0.01
49	0.30	0.06	0.05	0.06	0.06	0.05	0.03
51	2.00	0.60	0.20	0.30	0.20	0.10	0.60
52	0.63	0.19	0.06	0.09	0.16	0.03	0.09

Table 17. Total amount of time spend on labour for farm activities expressed in labour days. Family contains the time spend by the male, female and children working on the farm. In addition the amounts of time spend per crop is show in labour days.

	Labour input (labour days)			Labour per crop (labour days)					
Household number	Family	Male hired	Female hired	Coffee	Banana	Maize	Beans	Cassava	Other
1	207	15	0	40	25	60	29	9	71
2	253	6	6	11	66	27	60	9	92
3	187	16	30	85	6	55	56	2	28
5	142	6	10	56	21	2	29	12	38
7	444	42	40	223	11	114	18	0	160
8	490	43	11	32	3	102	89	39	279
10	541	0	0	76	2	63	92	39	269
11	600	0	0	272	39	106	31	64	89
12	504	2	1	89	97	37	1	54	230
14	404	29	15	53	236	55	19	12	71
15	240	0	0	61	42	3	39	19	77
16	387	68	18	145	7	33	48	36	204
21	454	1	0	170	25	10	51	19	179
24	266	23	52	128	44	8	20	40	101
31	344	124	23	100	30	124	19	1	217
33	394	4	6	114	104	26	28	3	129
37	252	32	16	111	26	2	59	1	100
39	365	156	8	295	61	8	92	4	69
40	178	29	10	121	11	2	45	4	34
41	341	75	41	100	141	52	73	4	88
43	675	14	0	56	107	16	31	15	463
45	638	20	6	46	35	193	64	31	296
48	235	1	1	61	36	30	24	5	80
49	193	6	3	53	13	20	20	11	85
51	193	161	19	67	44	81	82	1	100
52	309	96	62	80	10	106	71	0	198

Table 18. Household data on yields, land and labour productivities in kg/ha and labour days/ha, based on data from the logbooks

	Yields (kg)						Land productivity (kg/ha)						Labour input (labour days/ha)					
Household number	Coffee	Banana	Maize	Beans	Cassava	Others	Coffee	Banana	Maize	Beans	Cassava	Other	Coffee	Banana	Maize	Beans	Cassava	Others
1	1,292.9	3,080.0	4,106.8	221.8	185.1	110.0	2,245.6	6,889.9	4,458.2	385.3	803.9	955.3	69.8	36.8	65.6	125.5	40.2	615.3
2	260.7	1,507.0	720.0	482.8	1,347.0	633.0	1,036.9	18,529.7	4,296.3	921.9	10,716.8	15,108.6	44.5	523.5	163.5	284.8	71.3	2,207.1
3	1,025.9	858.0	923.0	375.9	100.0	174.5	1,275.1	6,592.4	327.8	149.5	497.2	433.8	105.8	31.3	19.4	55.6	9.2	69.6
5	1,358.5	847.0	0.0	656.5	116.0	83.0	2,550.4	4,300.7	2,000.0	1,150.3	508.2	1,090.8	104.9	68.4	8.0	128.9	51.9	499.5
7	3,831.2	1,947.0	4,144.6	213.4	6.5	143.0	20,092.7	47,341.7	9,315.5	1,343.0	204.5	2,249.9	1,170.0	174.6	257.1	283.8	524.9	2,512.2
8	417.0	418.0	566.6	1,625.2	2,600.1	810.1	5,406.3	25,127.1	2,203.8	6,321.5	25,283.9	10,503.7	412.1	122.0	396.9	864.5	377.0	3,621.0
10	1,793.5	825.0	569.6	750.2	657.7	983.5	2,200.4	3,128.5	279.5	490.9	1,613.7	1,206.6	92.8	5.0	30.8	150.0	96.6	330.0
11	1,441.2	1,397.0	0.0	0.0	1,537.5	779.0	8,900.0	66,663.4	2,000.0	500.0	23,736.7	24,053.2	1,676.6	1,200.8	233.1	236.0	993.9	2,753.0
12	1,404.8	594.0	906.5	0.0	1,403.4	442.5	6,698.7	7,660.6	5,043.1	500.0	15,614.7	7,385.2	425.9	811.0	203.5	17.9	598.9	3,835.4
14	0.0	1,210.0	0.0	19.8	143.5	201.5	1,000.0	4,254.3	2,000.0	36.0	979.4	1,375.2	182.4	537.8	124.2	86.0	84.6	487.0
15	1,534.7	1,650.0	404.0	271.6	644.9	1,286.0	17,177.9	128,443.8	20,349.5	5,472.2	21,654.9	43,184.0	677.3	2,133.5	145.7	1,955.4	628.4	2,584.9
16	4,981.3	1,683.0	1,933.0	730.6	2,178.5	1,108.5	24,269.9	76,035.6	7,063.5	2,135.8	31,842.3	10,801.7	707.8	210.7	120.1	349.9	522.3	1,986.9
21	2,410.3	2,134.0	438.2	1,975.5	1,657.5	373.7	14,920.7	24,499.2	8,137.0	9,783.3	20,521.2	6,939.3	1,053.5	182.8	188.6	626.9	240.3	3,328.2
24	6,334.8	6,413.0	1,510.1	931.2	1,278.5	1,369.5	12,500.6	31,292.1	2,980.0	5,880.2	20,183.1	21,619.7	252.3	138.1	15.7	319.8	630.8	1,591.9
31	1,438.2	1,617.0	1,232.4	271.6	349.3	1,552.0	12,916.6	56,108.3	3,953.0	2,439.2	15,682.9	23,230.6	901.6	670.4	397.4	421.8	35.3	3,255.0
33	543.2	374.0	890.0	357.7	110.0	39.5	4,065.3	5,407.7	4,163.4	1,784.9	2,058.3	739.1	849.8	975.4	123.0	350.2	46.8	2,409.8
37	2,388.1	2,849.0	5.2	1,164.8	270.1	275.0	17,762.1	75,428.6	77.0	5,544.6	16,073.0	16,363.0	828.7	516.4	34.7	704.3	38.8	5,969.8
39	2,892.4	2,970.0	105.0	510.9	778.5	365.0	5,262.3	14,614.0	668.6	650.7	3,304.9	4,648.4	537.0	193.0	50.0	292.9	18.3	880.7
40	5,176.2	847.0	320.0	291.0	588.7	10.5	10,763.6	14,971.0	1,829.9	887.5	13,465.6	240.2	251.3	125.2	11.0	346.7	99.2	781.0
41	956.3	2,376.0	22.8	930.4	3,007.4	253.0	2,897.0	25,955.5	80.4	3,945.9	31,886.4	1,788.3	302.8	997.5	183.1	769.2	38.6	618.8
43	624.4	4,598.0	102.5	1,043.7	708.0	243.5	876.6	19,951.1	143.9	4,688.3	3,975.6	2,734.6	79.0	300.5	21.9	351.4	85.1	5,202.3
45	0.0	1,023.0	9.0	300.0	144.0	187.0	1,000.0	52,029.5	88.9	3,949.1	7,108.4	9,231.0	900.1	1,142.4	1,906.3	2,094.2	1,534.0	14,622.5
48	293.4	1,369.5	170.2	244.0	110.0	72.0	3,352.9	48,373.9	2,593.0	4,461.4	5,028.2	6,582.4	693.7	826.6	460.7	1,105.2	227.0	7,358.3
49	329.5	1,375.0	191.0	90.8	693.5	597.0	5,423.5	46,639.4	1,572.0	597.7	15,220.9	19,654.4	876.0	279.8	167.5	336.3	246.1	2,781.9
51	973.2	1,452.0	95.4	133.5	0.0	458.0	1,619.2	11,200.8	158.7	266.5	10,000.0	762.0	110.6	218.6	135.4	408.9	5.7	165.6
52	575.7	935.0	265.5	933.4	123.5	169.5	3,058.2	23,028.0	1,410.4	2,380.0	3,936.3	1,800.8	427.5	166.5	565.3	452.8	531.6	2,102.4

Appendix C. Crop productivity and labour input graphs

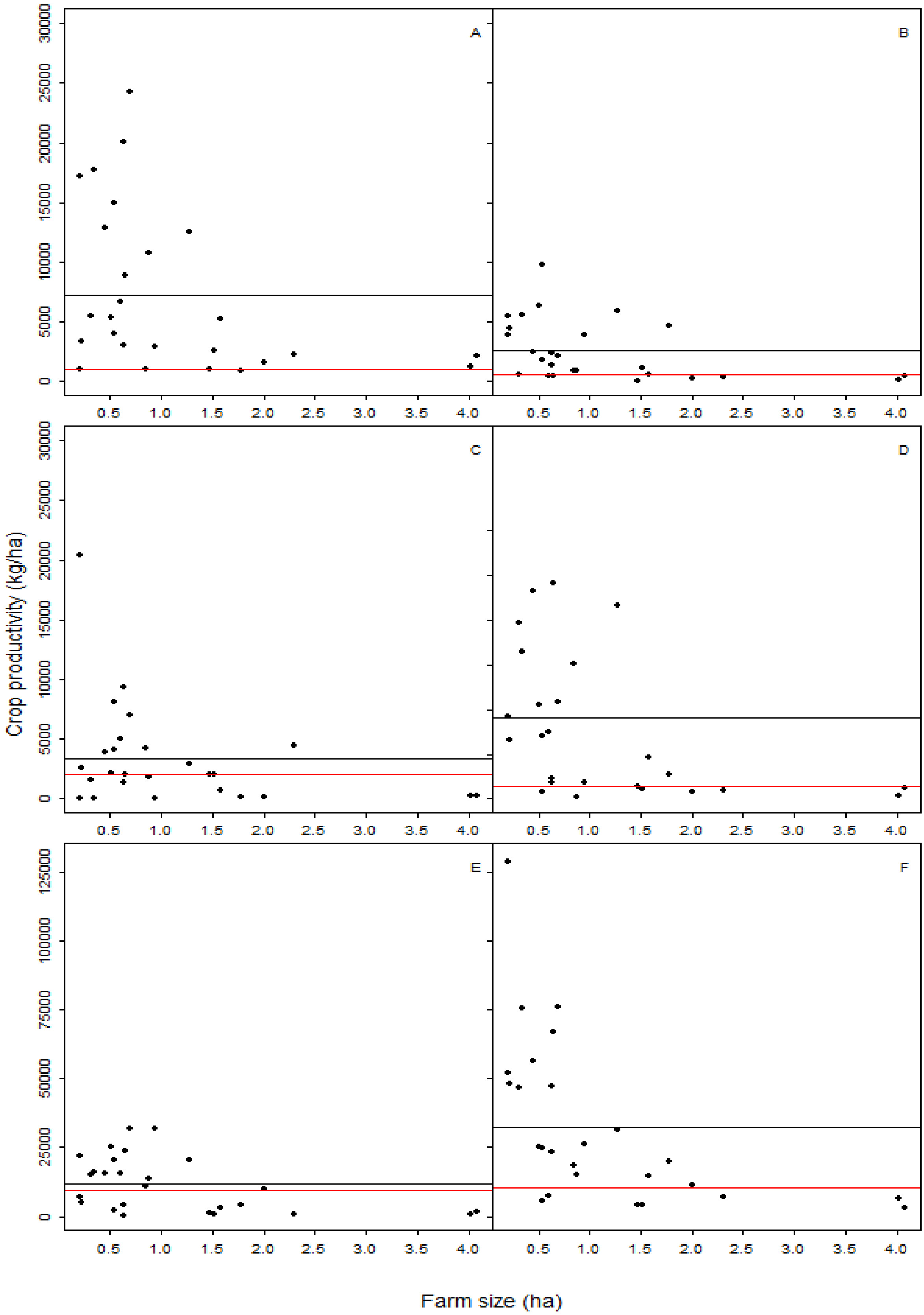

Figure 19. Crop productivities. The black line represents the average productivities from the logbook data. The red line is the average value from the literature. (A) coffee, (B) beans, (C) maize, (D) other, (E) cassava and (F) banana. Pay attion to the different y-axesses

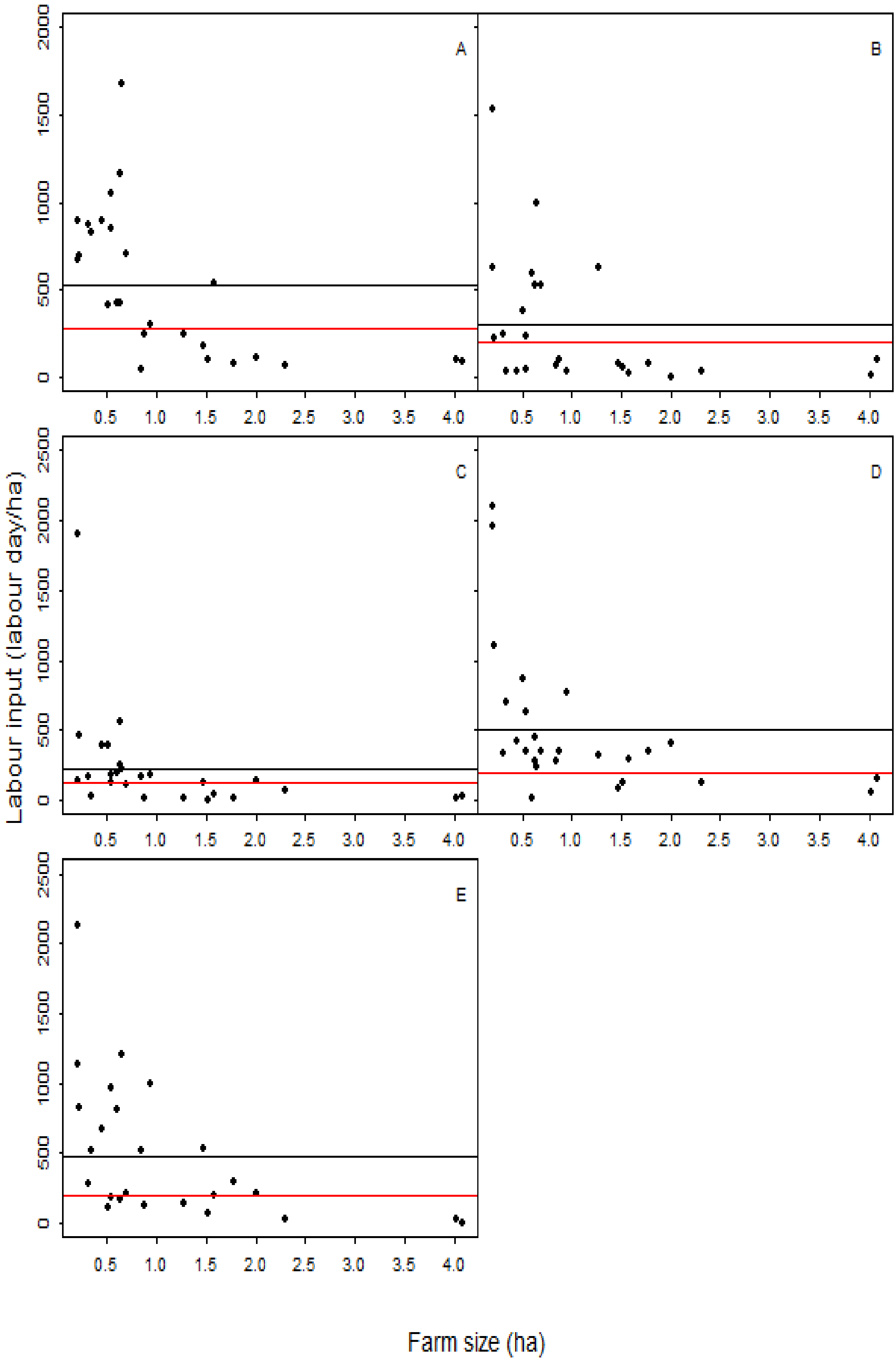

Figure 20. Labour input per crop. The red line indicates the labour input from literature and the black line the average labour input. (A) coffee, (B) cassava, (C) maize, (D) beans, (E) banana.

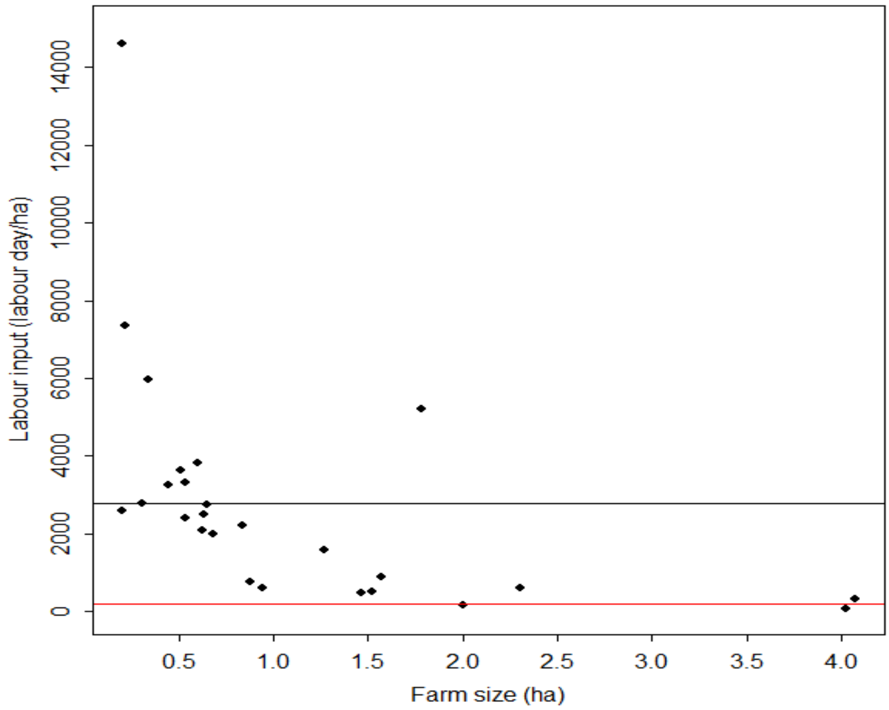

Figure 21. Labour input of other. The red line indicates the labour input from literature and the black line the average.

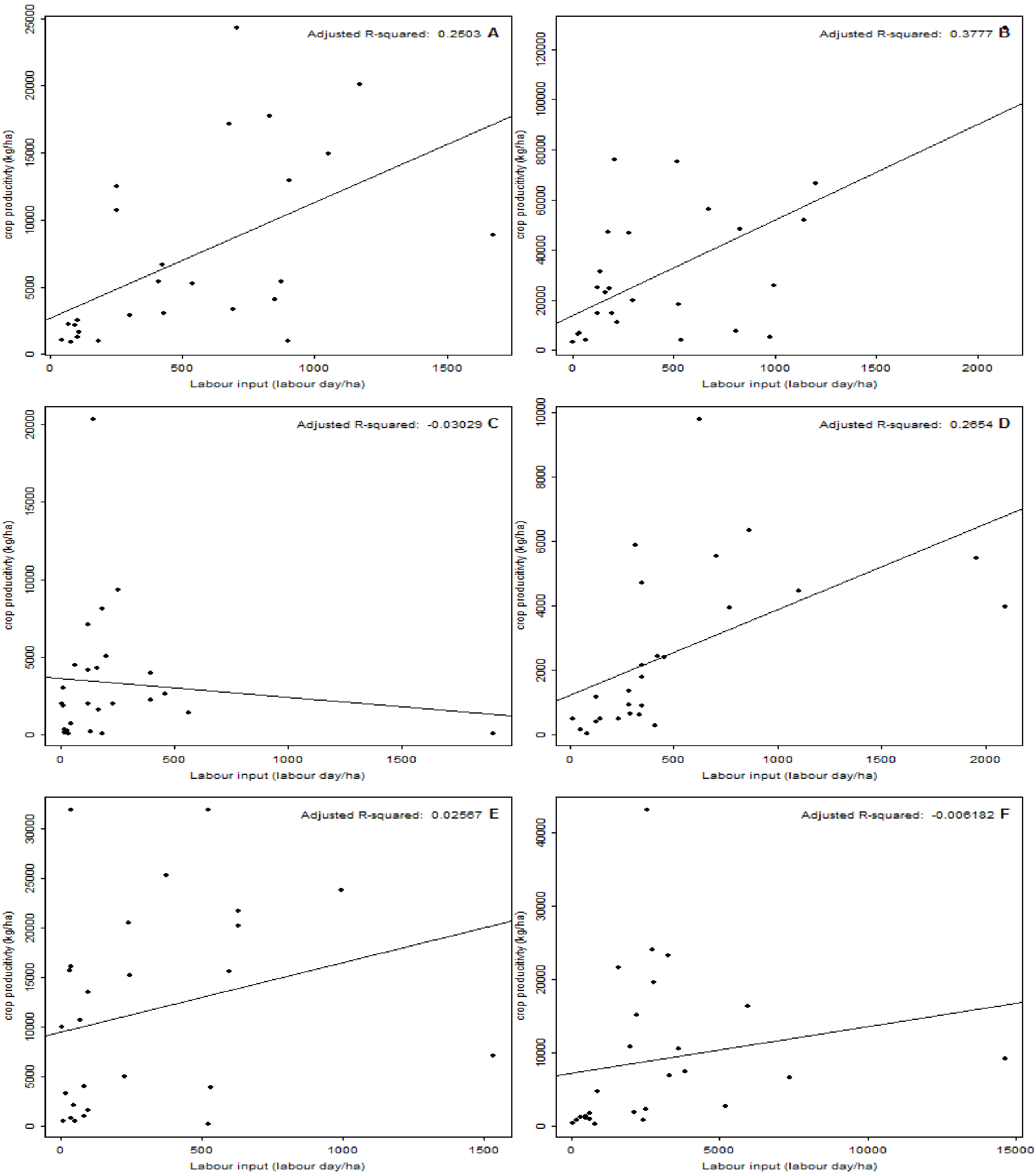

Figure 22. Crop productivity plotted against labour input. The black lines represent the relation between the two with the R-squared in each graph. (A) coffee, (B) banana, (C) maize, (D) beans, (E) cassava and (F) other. Negative R-squared indicates that the variance cannot be explained by the line.

Appendix D. Income from the scenarios

Table 19. Income from the current situation and the optimized income of the three scenarios per farm and the average of all the farms with the deviation.

Household number	Current (UGX)	Base run (UGX)	Constrained (UGX)	Free run (UGX)
1	2,973,700	3,365,350	1,837,511	3,193,035
2	3,228,000	2,253,403	734,901	1,443,049
3	1,393,600	1,513,832	1,541,838	8,233,782
5	1,496,200	2,038,832	-3,255,832	-1,401,685
7	7,202,700	4,630,544	0	7,879,639
8	465,950	1,911,002	1,531,070	2,556,538
10	2,344,150	2,557,566	-1,398,925	2,430,214
11	3,401,800	3,231,685	2,405,693	7,255,406
12	562,000	2,109,561	-868,548	-662,216
14	592,500	-57,545	-2,885,880	-2,705,732
15	363,000	3,966,872	3,011,557	3,437,366
16	1,002,200	7,670,263	9,659,339	15,587,076
21	1,086,100	4,527,995	-3,245,758	-1,943,452
24	3,836,700	11,480,203	10,902,110	13,002,435
31	3,142,100	2,613,304	4,218,483	7,915,379
33	36,000	794,530	66,937	333,613
37	2,643,200	4,086,100	3,926,260	6,713,809
39	2,587,150	5,198,002	3,654,550	5,470,463
40	1,753,200	5,774,111	3,753,576	4,969,772
41	984,300	3,278,270	6,661,783	9,104,201
43	758,200	3,397,488	6,286,653	10,043,835
45	445,500	5,151	-1,885,532	160,236
48	2,631,150	535,475	65,960	1,350,251
49	85,800	1,883,608	1,837,967	4,013,485
51	1,804,900	552,646	2,220,339	3,752,947
52	4,769,550	299,540	1,805,561	4,342,816
average	1,984,217	3,062,223	2,022,370	4,479,856
std.dv	1,632,025	2,507,527	3,514,688	4,471,773

Appendix E. Land calculation script

```
### LAND data ###
setwd("M:\\My Documents\\Master thesis stuff\\R models\\")
##############data to be accessed################

Farmers  <-read.delim("M:\\My Documents\\Master thesis stuff\\R models\\Data
files input\\Text files\\Combined.farmers.dataset.version.2.txt")

Land.per  <-read.table("M:\\My Documents\\Master thesis stuff\\R
models\\Data files input\\Text files\\Land.division.per.txt", header=TRUE)

############# Parameters ############
attach(Farmers)
attach(Land.per)

names(Farmers)
names(Land.per)

# From acres to hectares, Area is in acres, 0.4... is the conversion factor
to calculate hectares, 0.05 is the area on which the house stands with a
court
Max.area            = (Area * 0.404686) - 0.02

##############################################################
########### Land calcultaions based on questionaire for focus group
discussions ###########
# Here the area per crop is calculated from the percentages that the farmers
gave in the FGD. the area depends on the Max.area from above

Coffee.area         = Max.area * (Per.Coffee   / 100)
Banana.area         = Max.area * (Per.Banana   / 100)
Maize.area          = Max.area * (Per.Maize    / 100)
Beans.area          = Max.area * (Per.Beans    / 100)
Cassava.area        = Max.area * (Per.Cassava  / 100)
Other.area          = Max.area * (Per.Other    / 100)

Land.area           = cbind(Coffee.area, Banana.area, Maize.area, Beans.area,
Cassava.area, Other.area)
summary(Land.area)

###########################################
######### saving data ##########

Land.use            = data.frame(HHCode, Max.area, Land.area,
Desired.land.area, Difference.land.areas)

setwd("M:\\My Documents\\Master thesis stuff\\R models\\Data files
output\\Intermediaries\\")
write.table(Land.use, file = "Farmers.area.txt", dec = ",")
write.table(Land.use, file = "Farmers.area2.txt", dec = ".")
write.csv(Land.use, file = "Farmers.area.csv")
```

Parameter calculation script

```
###### Farmer calculations ######
# Here the necessary data is produced such that the models can run.
# the excel data from Combined.farmers.dataset will be the basis on which
the caculations will run

setwd("M:\\My Documents\\Master thesis stuff\\R models\\")
##############data to be accessed################

Farmers          <-read.delim("M:\\My Documents\\Master thesis stuff\\R
models\\Data files input\\Text
files\\Combined.farmers.dataset.version.2.txt")
cropcalories       <-read.delim("M:\\My Documents\\Master thesis stuff\\R
models\\Data files input\\Text files\\Calories.txt")
literature.prod <-read.delim("M:\\My Documents\\Master thesis stuff\\R
models\\Data files input\\Text files\\literature.productivities.txt")

Farmers.area    <-read.table("M:\\My Documents\\Master thesis stuff\\R
models\\Data files output\\Intermediaries\\Farmers.area.txt", header=TRUE,
dec = ",")

############## Parameters #############

attach(Farmers)
attach(Farmers.area)
attach(cropcalories)
attach(literature.prod)

names(Farmers)
names(Farmers.area)
names(cropcalories)
names(literature.prod)

################ labour #######################
# here the amount of labourdays is calulated on the basis that a labour day
is 7 hours of work
# it is not only done over the total amount of labour on the whole farm but
also per crop.
# five groups can work on the farm, the man, the woman, the child(ren),
hired men, hired women
# since productivity of children is lower the assumption is they have a
production that's half of the adults.

#### farm total #####
labour_day_M   = Farmers$Labour.M / 7
labour_day_F   = Farmers$Labour.F /7
labour_day_C      = Farmers$Labour.C / 7 *0.5
labour_day_MH     = Farmers$Labour.MH / 7
labour_day_FH     = Farmers$Labour.FH / 7

Farm.total.labday= labour_day_M + labour_day_F + labour_day_C +
labour_day_MH + labour_day_FH
Farm.family.labday= labour_day_M + labour_day_F + labour_day_C
Farm.hired.labday = labour_day_MH + labour_day_FH

#### labour days per crop per labour group ####

LabDay.M.Cof   = Farmers$M.coffee / 7
```

```
LabDay.M.Ban      = Farmers$M.banana / 7
LabDay.M.Ma       = Farmers$M.maize / 7
LabDay.M.Bea      = Farmers$M.beans / 7
LabDay.M.Cas      = Farmers$M.cassava / 7
LabDay.M.Oth   = Farmers$M.other / 7

LabDay.F.Cof      = Farmers$F.coffee / 7
LabDay.F.Ban      = Farmers$F.banana / 7
LabDay.F.Ma       = Farmers$F.maize / 7
LabDay.F.Bea      = Farmers$F.beans / 7
LabDay.F.Cas      = Farmers$F.cassava / 7
LabDay.F.Oth   = Farmers$F.other / 7

LabDay.C.Cof      = Farmers$C.coffee / 7 * 0.5
LabDay.C.Ban      = Farmers$C.banana / 7 * 0.5
LabDay.C.Ma       = Farmers$C.maize / 7 * 0.5
LabDay.C.Bea      = Farmers$C.beans / 7 * 0.5
LabDay.C.Cas      = Farmers$C.cassava / 7 * 0.5
LabDay.C.Oth   = Farmers$C.other / 7 * 0.5

LabDay.MH.Cof     = Farmers$M.H.coffee / 7
LabDay.MH.Ban     = Farmers$M.H.banana / 7
LabDay.MH.Ma      = Farmers$M.H.maize / 7
LabDay.MH.Bea     = Farmers$M.H.beans / 7
LabDay.MH.Cas     = Farmers$M.H.cassava / 7
LabDay.MH.Oth = Farmers$M.H.other / 7

LabDay.FH.Cof     = Farmers$F.H.coffee / 7
LabDay.FH.Ban     = Farmers$F.H.banana / 7
LabDay.FH.Ma      = Farmers$F.H.maize / 7
LabDay.FH.Bea     = Farmers$F.H.beans / 7
LabDay.FH.Cas     = Farmers$F.H.cassava / 7
LabDay.FH.Oth = Farmers$F.H.other / 7


#### labour days per crop summed groups ####

LabDay.coffee       = LabDay.M.Cof + LabDay.F.Cof + LabDay.C.Cof +
LabDay.MH.Cof + LabDay.FH.Cof
LabDay.banana       = LabDay.M.Ban + LabDay.F.Ban + LabDay.C.Ban +
LabDay.MH.Ban + LabDay.FH.Ban
LabDay.maize        = LabDay.M.Ma + LabDay.F.Ma + LabDay.C.Ma + LabDay.MH.Ma
+ LabDay.FH.Ma
LabDay.beans        = LabDay.M.Bea + LabDay.F.Bea + LabDay.C.Bea +
LabDay.MH.Bea + LabDay.FH.Bea
LabDay.cassava    = LabDay.M.Cas + LabDay.F.Cas + LabDay.C.Cas +
LabDay.MH.Cas + LabDay.FH.Cas
LabDay.other     = LabDay.M.Oth + LabDay.F.Oth + LabDay.C.Oth + LabDay.MH.Oth
+ LabDay.FH.Oth

labourset    = data.frame(LabDay.coffee, LabDay.banana, LabDay.maize,
LabDay.beans, LabDay.cassava, LabDay.other, Farm.total.labday,
Farm.family.labday)

###################### Productivity of the various crops
##########################
# here the parameters for the crops are specified. the crops are coffee,
banana, maize, beans, cassava and others
```

```
# others are all the other crops that the farmers grow, they are lumped
togheter because they are not a major source
# of food or income in most cases.
# the prices of the products are taken from the farmgain and ifpri and the
ugandan coffee authority websites.
# the yields are calculated from the data that the farmers collected
themselfes they are yields in fresh weight.
# the productivities are in kg/ha, UGX/ha, kg/labourday, UGX/labourday, some
farmers do not grow the specified crop or tehy did not harvest anything due
to pests
# then a value was assigned to them to make it possible to calculate with
the farmers (ifelse function) the value is acquired from literature
# the costs of the crops are based on what the farmers have recorded
themselves in UGX, labour costs for the hired labour and the input costs
# however the second costs is also taking the amount of work that the
household self is investing the crop by estimating the
# value of a labourday 3000 UGX.

coffee_RTprice  = cropcalories[9,4]
coffee_WSprice  = cropcalories[9,9]
coffee_revenue   = Coffee * coffee_WSprice
coffee_prod_kg   = Coffee / Coffee.area
coffee_prod_kg  = ifelse(coffee_prod_kg == 0, literature.prod[1,9],
coffee_prod_kg)
coffee_DM_yield = Coffee * cropcalories[9,5]
coffee_DM_prod  = coffee_DM_yield / Coffee.area
coffee_prod_sh   = coffee_revenue / Coffee.area
coffee_prod_lh  = LabDay.coffee / Coffee.area
coffee_prod_la  = Coffee / LabDay.coffee
coffee_prod_sl  = coffee_revenue / LabDay.coffee
coffee_costs    = L.costs.coffee + Input.cost.coffee
coffee_costs2   = LabDay.coffee * 3000 + Input.cost.coffee
coffee_in_cost  = Input.cost.coffee / Coffee.area
coffee_lb_cost  = L.costs.coffee / Coffee.area

banana_RTprice  = cropcalories[3,4]
banana_WSprice  = cropcalories[3,9]
banana_revenue   = Banana * banana_WSprice
banana_kcal_kg  = cropcalories[3,2] * 10
banana_kcal_pr  = banana_kcal_kg / banana_RTprice
banana_prod_kg   = Banana / Banana.area
banana_prod_kg  = ifelse(banana_prod_kg == 0,  literature.prod[2,9],
banana_prod_kg)
banana_DM_yield = (((Banana * (1 - cropcalories[3,6])) * cropcalories[3,5])
* cropcalories[3,7])
banana_DM_prod  = banana_DM_yield / Banana.area
banana_prod_sh   = banana_revenue / Banana.area
banana_prod_lh  = LabDay.banana / Banana.area
banana_prod_la  = Banana / LabDay.banana
banana_prod_sl  = banana_revenue / LabDay.banana
banana_costs    = L.costs.banana + Input.cost.banana
banana_costs2   = LabDay.banana * 3000 + Input.cost.banana
banana_in_cost  = Input.cost.banana / Banana.area
banana_lb_cost  = L.costs.banana / Banana.area

maize_RTprice   = cropcalories[1,4]
maize_WSprice   = cropcalories[1,9]
maize_revenue     = Maize * maize_WSprice
```

```
maize_kcal_kg   = cropcalories[1,2] * 10
maize_kcal_pr   = maize_kcal_kg / maize_RTprice
maize_prod_kg    = (Maize / Maize.area) * 0.5
maize_prod_kg   = ifelse(maize_prod_kg == 0, literature.prod[3,9], 
maize_prod_kg)
maize_DM_yield  = Maize * cropcalories[1,5]
maize_DM_prod   = maize_DM_yield / Maize.area
maize_prod_sh      = (maize_revenue / Maize.area) * 0.5
maize_prod_lh   = (LabDay.maize / Maize.area) * 0.5
maize_prod_la   = (Maize / LabDay.maize) * 0.5
maize_prod_sl   = (maize_revenue / LabDay.maize) * 0.5
maize_costs     = L.costs.maize  + Input.cost.maize
maize_costs2    = LabDay.maize * 3000 + Input.cost.maize
maize_in_cost   = Input.cost.maize / Maize.area
maize_lb_cost   = L.costs.maize / Maize.area

# 0,5 to take the double maize growing season into account kg/ha


beans_RTprice   = cropcalories[5,4]
beans_WSprice   = cropcalories[5,9]
beans_revenue      = Beans * beans_WSprice
beans_kcal_kg   = cropcalories[5,2] * 10
beans_kcal_pr   = beans_kcal_kg / beans_RTprice
beans_prod_kg      = (Beans *  cropcalories[5,8]) / Beans.area
beans_prod_kg   = ifelse(beans_prod_kg == 0, literature.prod[4,9], 
beans_prod_kg)
beans_DM_yield  = Beans * cropcalories[5,5]
beans_DM_prod   = beans_DM_yield / Beans.area
beans_prod_sh      = beans_revenue / Beans.area
beans_prod_lh   = LabDay.beans / Beans.area
beans_prod_la   = Beans / LabDay.beans
beans_prod_sl   = beans_revenue / LabDay.beans
beans_costs     = L.costs.beans  + Input.cost.beans
beans_costs2    = LabDay.beans * 3000 + Input.cost.beans
beans_in_cost   = Input.cost.beans / Beans.area
beans_lb_cost   = L.costs.beans / Beans.area

cassava_RTprice = cropcalories[7,4]
cassava_WSprice = cropcalories[7,9]
cassava_revenue  = Cassava * cassava_WSprice
cassava_kcal_kg = cropcalories[7,2] * 10
cassava_kcal_pr = cassava_kcal_kg / cassava_RTprice
cassava_prod_kg  = Cassava / Cassava.area
cassava_prod_kg = ifelse(cassava_prod_kg == 0, literature.prod[5,9], 
cassava_prod_kg)
cassava_DM_yield= Cassava *  cropcalories[7,5]
cassava_DM_prod = cassava_DM_yield / Cassava.area
cassava_prod_sh  = cassava_revenue / Cassava.area
cassava_prod_lh = ifelse(LabDay.cassava == 0, mean(LabDay.cassava), 
LabDay.cassava) / Cassava.area
cassava_prod_la = Cassava / LabDay.cassava
cassava_prod_sl = cassava_revenue / LabDay.cassava
cassava_costs   = L.costs.cassava + Input.cost.cassava
cassava_costs2  = LabDay.cassava * 3000 + Input.cost.cassava
cassava_in_cost = Input.cost.cassava / Cassava.area
cassava_lb_cost = L.costs.cassava / Cassava.area
```

```
other_RTprice   = cropcalories[10,4]
other_WSprice   = cropcalories[10,9]
other_revenue      = Others * other_WSprice
other_kcal_kg   = cropcalories[10,2] * 10
other_kcal_pr   = other_kcal_kg / other_RTprice
other_prod_kg      = Others / Other.area
other_prod_kg   = ifelse(other_prod_kg == 0, literature.prod[6,9],
other_prod_kg)
other_DM_yield  = Others * cropcalories[10,5]
other_DM_prod   = other_DM_yield / Other.area
other_prod_sh      = other_revenue / Other.area
other_prod_lh   = LabDay.other / Other.area
other_prod_la   = Others / LabDay.other
other_prod_sl   = other_revenue / LabDay.other
other_costs     = L.costs.other +  Input.cost.other
other_costs2    = LabDay.other * 3000 + Input.cost.other
other_in_cost   = Input.cost.other / Other.area
other_lb_cost   = L.costs.other / Other.area


Crop.revenue     = coffee_revenue + banana_revenue + maize_revenue +
beans_revenue + cassava_revenue + other_revenue

coffee.data     = cbind(coffee_revenue, coffee_prod_kg, coffee_DM_yield,
coffee_DM_prod, coffee_prod_sh, coffee_prod_lh , coffee_prod_la,
coffee_prod_sl, coffee_costs, coffee_costs2, coffee_in_cost, coffee_lb_cost)
banana.data     = cbind(banana_revenue, banana_kcal_kg, banana_prod_kg,
banana_DM_yield, banana_DM_prod, banana_prod_sh, banana_prod_lh ,
banana_prod_la, banana_prod_sl, banana_costs, banana_costs2, banana_in_cost,
banana_lb_cost)
maize.data      = cbind(maize_revenue, maize_kcal_kg, maize_prod_kg,
maize_DM_yield, maize_DM_prod, maize_prod_sh, maize_prod_lh , maize_prod_la,
maize_prod_sl, maize_costs, maize_costs2, maize_in_cost, maize_lb_cost)
beans.data      = cbind(beans_revenue, beans_kcal_kg, beans_prod_kg,
beans_DM_yield, beans_DM_prod, beans_prod_sh, beans_prod_lh ,beans_prod_la,
beans_prod_sl, beans_costs, beans_costs2, beans_in_cost, beans_lb_cost)
cassava.data    = cbind(cassava_revenue, cassava_kcal_kg, cassava_prod_kg,
cassava_DM_yield, cassava_DM_prod, cassava_prod_sh, cassava_prod_lh ,
cassava_prod_la, cassava_prod_sl, cassava_costs, cassava_costs2,
cassava_in_cost, cassava_lb_cost)
others.data     = cbind(other_revenue, other_kcal_kg, other_prod_kg,
other_DM_yield, other_DM_prod, other_prod_sh, other_prod_lh, other_prod_la,
other_prod_sl, other_costs, other_costs2, other_in_cost, other_lb_cost)

crop.parameters = cbind(coffee_RTprice, coffee_WSprice, banana_RTprice,
banana_WSprice, maize_RTprice, maize_WSprice, beans_RTprice, beans_WSprice,
cassava_RTprice, cassava_WSprice, other_RTprice, other_WSprice,
banana_kcal_pr, maize_kcal_pr, beans_kcal_pr, cassava_kcal_pr,
other_kcal_pr)
crop.dataset    = cbind(coffee.data, banana.data, maize.data, beans.data,
cassava.data, others.data)
revenue         = cbind(coffee_revenue, banana_revenue, maize_revenue,
beans_revenue, cassava_revenue, other_revenue, Crop.revenue)

######### farm and household economic parameters #########
# the different incomes and expenses in UGX
# in Farmexpenses the labour costs that the farmers have recorded are
included
```

```
HH.income           = Income.farm + Income.offfarm
HH.expenses         = Farmexpenses + HHexpenses + Investments + Input.costs
Farm.expenses       = Farmexpenses + Investments + Input.costs
Farm.income         = Income.farm
Farm.revenue        = Crop.revenue
HH.income.rev       = Farm.revenue + Income.offfarm
total.labour.costs = Farm.total.labday * 3000
food.expense.propo = Food.expenses / Income.farm
Farm.labour.cost    = Labour.costs / Farm.hired.labday
Farm.labour.cost    = ifelse(Labour.costs == 0 , 999999,
ifelse(Farm.hired.labday == 0, 999999, Farm.labour.cost))

household.economics= cbind(Farm.income, Farm.revenue, HH.income.rev,
HH.expenses, Farm.expenses, total.labour.costs)

########################## datasets ######################################

para.farmers = cbind(HHCode, household.economics, labourset, crop.dataset,
revenue)

setwd("M:\\My Documents\\Master thesis stuff\\R models\\Data files
output\\Intermediaries\\")
write.csv(para.farmers, file = "productivity.farmers.csv")
write.table(para.farmers, file = "productivity.farmers.txt", dec = ",")
write.table(para.farmers, file = "productivity.farmers2.txt", dec = ".")
write.table(crop.parameters, file = "crop.parameters.txt", dec = ",")
```

Food self-sufficiency script

```
setwd("M:\\My Documents\\Master thesis stuff\\R models\\")
######## food self suffiency calculation #######

Farmers                 = read.delim("M:\\My Documents\\Master thesis stuff\\R models\\Data files input\\Text files\\Combined.farmers.dataset.version.2.txt")
cropcalories            = read.delim("M:\\My Documents\\Master thesis stuff\\R models\\Data files input\\Text files\\Calories.txt")

productivity.farmers    = read.table("M:\\My Documents\\Master thesis stuff\\R models\\Data files output\\Intermediaries\\productivity.farmers.txt", header=TRUE, dec = ",")
Farmers.area            = read.table("M:\\My Documents\\Master thesis stuff\\R models\\Data files output\\Intermediaries\\Farmers.area.txt", header=TRUE, dec = ",")

Farmers.base            = read.table("M:\\My Documents\\Master thesis stuff\\R models\\Data files output\\Runs\\base results.txt", header = TRUE, dec = ".")
Farmers.free            = read.table("M:\\My Documents\\Master thesis stuff\\R models\\Data files output\\Runs\\Free results.txt", header = TRUE, dec = ".")
Farmers.const           = read.table("M:\\My Documents\\Master thesis stuff\\R models\\Data files output\\Runs\\Constrained results.txt", header = TRUE, dec = ".")

############### parameters ################

attach(Farmers)
attach(productivity.farmers)
attach(Farmers.area)
attach(cropcalories)

names(Farmers)
names(productivity.farmers)
names(cropcalories)
names(Farmers.area)
names(Farmers.base)
names(Farmers.free)
names(Farmers.const)

##################### Food self suffiency ################
# the amount of energy that the household produces is estimated based on the fresh weight yields that the farmers recorded.
# coffee is excluded because the farmers do not consume it in any form.
# then the energy requirements of the household are estimated for one year. based the amount of calories the memebers need based on the age
# then a eventual gap can be estimated, how much additional food is necessary for the HH? pos = food needs to be bought/produced
# a ratio is calculated and then the ones below 1 are selected.
# all are in kcal/year and ratios

HH_energy_req               = Member.HH.from18 * 2400 * 365 + Member.HH.to18 * 1800 * 365

## current ##
```

```
HH_energy_prod.cur          = ((Banana * banana_kcal_kg) + (Maize *
maize_kcal_kg) + (Beans * beans_kcal_kg) + (Cassava * cassava_kcal_kg) +
(Others * other_kcal_kg))

## modeled base ##
HH_energy_prod.mod.base     = ((Farmers.base$area.banana * banana_prod_kg *
banana_kcal_kg) + (Farmers.base$area.maize * maize_prod_kg * maize_kcal_kg)
+ (Farmers.base$area.beans * beans_prod_kg * beans_kcal_kg) +
(Farmers.base$area.cassava * cassava_prod_kg * cassava_kcal_kg) +
(Farmers.base$area.others * other_prod_kg * other_kcal_kg))

## modeled free ##
HH_energy_prod.mod.free     = ((Farmers.free$area.banana * banana_prod_kg *
banana_kcal_kg) + (Farmers.free$area.maize * maize_prod_kg * maize_kcal_kg)
+ (Farmers.free$area.beans * beans_prod_kg * beans_kcal_kg) +
(Farmers.free$area.cassava * cassava_prod_kg * cassava_kcal_kg) +
(Farmers.free$area.others * other_prod_kg * other_kcal_kg))

## modeled constrainted ##
HH_energy_prod.mod.const    = ((Farmers.const$area.banana * banana_prod_kg *
banana_kcal_kg) + (Farmers.const$area.maize * maize_prod_kg * maize_kcal_kg)
+ (Farmers.const$area.beans * beans_prod_kg * beans_kcal_kg) +
(Farmers.const$area.cassava * cassava_prod_kg * cassava_kcal_kg) +
(Farmers.const$area.others * other_prod_kg * other_kcal_kg))


##### food self-sufficiency ratios #####
fss_ratio.cur               = HH_energy_prod.cur / HH_energy_req
fss_ratio.mod.base          = HH_energy_prod.mod.base[1:26] / HH_energy_req
fss_ratio.mod.free          = HH_energy_prod.mod.free[1:26] / HH_energy_req
fss_ratio.mod.const         = HH_energy_prod.mod.const[1:26] / HH_energy_req

fss_ratio                   = cbind(HHCode, fss_ratio.cur, fss_ratio.des,
fss_ratio.mod.base, fss_ratio.mod.free, fss_ratio.mod.const)

##### datasets #####

FSS.cal                     = cbind(HH_energy_req, HH_energy_prod.cur,
HH_energy_prod.mod.base, HH_energy_prod.mod.free, HH_energy_prod.mod.const)
food.selfsufficiency        = data.frame(HHCode, FSS.cal[1:26,],
fss_ratio[1:26,])

setwd("M:\\My Documents\\Master thesis stuff\\R models\\Data files
output\\Intermediaries\\")
write.csv(food.selfsufficiency, file = "Food.selfsufficiency.csv")
write.table(food.selfsufficiency, file = "Food.selfsufficiency.txt", dec =
",")
write.table(food.selfsufficiency, file = "Food.selfsufficiency2.txt", dec =
".")


##### plots ####

par(mfrow=c(2,2))
current     = fss_ratio[order(fss_ratio[,2]),]
barplot(current[,2], names.arg=current[,1], ylim = c(0,13),
        main ="Current food self-sufficiency ratio", xlab = "Household
number", ylab = "Food self-sufficiency ratio (-)")
```

```
abline(h = 1, col = "red", lwd = 2)

base      = fss_ratio[order(fss_ratio[,4]),]
barplot(base[,4], names.arg=base[,1],ylim = c(0,13),
        main ="Base food self-sufficiency ratio", xlab = "Household number",
ylab = "Food self-sufficiency ratio (-)")
abline(h = 1, col = "red", lwd = 2)

constrained     = fss_ratio[order(fss_ratio[,6]),]
barplot(constrained[,6], names.arg=constrained[,1], ylim = c(0,13),
        main ="Constrained food self-sufficiency ratio", xlab = "Household
number", ylab = "Food self-sufficiency ratio (-)")
abline(h = 1, col = "red", lwd = 2)

free      = fss_ratio[order(fss_ratio[,5]),]
barplot(free[,5], names.arg=free[,1], ylim = c(0,13),
        main ="Free food self-sufficiency ratio", xlab = "Household number",
ylab = "Food self-sufficiency ratio (-)")
abline(h = 1, col = "red", lwd = 2)


plot.new()
par(mfrow= c(1,1))

HHCode.order    = HHCode[order(fss_ratio.mod.base)]
FSS.base        = fss_ratio.mod.base[order(fss_ratio.mod.base)]

base.const.dif = fss_ratio.mod.const - fss_ratio.mod.base
base.const.dif = ifelse(base.const.dif < 0, 0,
base.const.dif)[order(fss_ratio.mod.base)]
const.free.dif = fss_ratio.mod.free - fss_ratio.mod.const
const.free.dif = ifelse(const.free.dif < 0, 0,
const.free.dif)[order(fss_ratio.mod.base)]
FSSGRAPH        = cbind(HHCode.order, FSS.base, base.const.dif,
const.free.dif)

barplot(t(FSSGRAPH[,2:4]), names.arg = HHCode.order, ylim = c(0,13), col =
c("deepskyblue", "dodgerblue2", "dodgerblue4"),
        xlab = "Household number", ylab = "Food self-sufficiency ratio (-)")
legend("topleft", fill = c("deepskyblue", "dodgerblue2", "dodgerblue4"), cex
= 0.8,
       legend = c("Base", "Constrained", "Free"), bty="n")
abline(h = 1, col = "red", lwd = 2)


cbind(free[,1], base.const.dif, const.free.dif)
```

Food security script

```
setwd("M:\\My Documents\\Master thesis stuff\\R models\\")
############# food security ###################

Farmers              = read.delim("M:\\My Documents\\Master thesis stuff\\R
models\\Data files input\\Text
files\\Combined.farmers.dataset.version.2.txt")
cropcalories         = read.delim("M:\\My Documents\\Master thesis stuff\\R
models\\Data files input\\Text files\\Calories.txt")
foodbasket           = read.delim("M:\\My Documents\\Master thesis stuff\\R
models\\Data files input\\Text files\\food basket division.txt")

Farmers.area         = read.table("M:\\My Documents\\Master thesis stuff\\R
models\\Data files output\\Intermediaries\\Farmers.area.txt", header=TRUE,
dec = ",")
productivity.farmers = read.table("M:\\My Documents\\Master thesis stuff\\R
models\\Data files output\\Intermediaries\\productivity.farmers.txt",
header=TRUE, dec = ",")
crop.parameters      = read.table("M:\\My Documents\\Master thesis stuff\\R
models\\Data files output\\Intermediaries\\crop.parameters.txt",
header=TRUE, dec = ",")
food.selfsufficiency = read.table("M:\\My Documents\\Master thesis stuff\\R
models\\Data files output\\Intermediaries\\Food.selfsufficiency.txt",
header=TRUE, dec = ",")

Farmers.base          = read.table("M:\\My Documents\\Master thesis stuff\\R
models\\Data files output\\Runs\\base results.txt", header = TRUE, dec =
".")
Farmers.free          = read.table("M:\\My Documents\\Master thesis stuff\\R
models\\Data files output\\Runs\\Free results.txt", header = TRUE, dec =
".")
Farmers.const         = read.table("M:\\My Documents\\Master thesis stuff\\R
models\\Data files output\\Runs\\Constrained results.txt", header = TRUE,
dec = ".")


###### parameters #########
attach(Farmers)
attach(productivity.farmers)
attach(not.fss.fa)
attach(Farmers.area)
attach(cropcalories)
attach(foodbasket)
attach(crop.parameters)

names(Farmers)
names(Productivity)
names(not.fss.fa)
names(Farmers.area)
names(cropcalories)
names(foodbasket)
names(crop.parameters)
names(Farmers.base)

## food basket ##
# the price per kcal is calculated based on a food basket (basket of goods)
such that multiple products are bought
```

```
# it depends on the percentage of the products in the basket what the price
will be. thus the unit is kcal/UGX

foodbasket.kcal.pr= (banana_kcal_pr * foodbasket[1,2]) + (maize_kcal_pr *
foodbasket[2,2]) + (beans_kcal_pr * foodbasket[3,2]) + (cassava_kcal_pr *
foodbasket[4,2]) + (other_kcal_pr * foodbasket[5,2])

############# Food security calculations ###################
# How much additional food does the HH need to buy to be food secure?
# one FS ratio is only based on what the farm produces so could the farm be
food secure; can coffee pay for the rest
# buying energy with left over money
# the balance is in UGX and calculated on the basis that the household
should have enought money to spend to pay for food
# the kcal bought are then in kcal again based on the amount of money left
and the kcal/UGX such that the ratio afterwards is all in kcal

Farm.balance.cur            = ifelse(Farm.income > Farm.expenses, Farm.income
- Farm.expenses, 0)
Kcal_bought.farm.cur        = Farm.balance.cur * foodbasket.kcal.pr
fs_ratio.f.cur              = (HH_energy_prod.cur[1:26] +
Kcal_bought.farm.cur[1:26]) / HH_energy_req

Farm.balance.mod.base       = ifelse(Farmers.base$income.vector >
Farm.expenses, Farmers.base$income.vector - Farm.expenses, 0)
Kcal_bought.farm.mod.base   = Farm.balance.mod.base * foodbasket.kcal.pr
fs_ratio.f.mod.base         = (HH_energy_prod.mod.base[1:26] +
Kcal_bought.farm.mod.base[1:26]) / HH_energy_req

Farm.balance.mod.free       = ifelse(Farmers.free$income.vector >
Farm.expenses, Farmers.free$income.vector - Farm.expenses, 0)
Kcal_bought.farm.mod.free   = Farm.balance.mod.free * foodbasket.kcal.pr
fs_ratio.f.mod.free         = (HH_energy_prod.mod.free[1:26] +
Kcal_bought.farm.mod.free[1:26]) / HH_energy_req

Farm.balance.mod.const      = ifelse(Farmers.const$income.vector >
Farm.expenses, Farmers.const$income.vector - Farm.expenses, 0)
Kcal_bought.farm.mod.const = Farm.balance.mod.const * foodbasket.kcal.pr
fs_ratio.f.mod.const        = (HH_energy_prod.mod.const[1:26] +
Kcal_bought.farm.mod.const[1:26]) / HH_energy_req

############# data saving in txt files ############

Ratio.fsecurity      = cbind(HHCode, fs_ratio.f.cur, fs_ratio.f.mod.base,
fs_ratio.f.mod.free, fs_ratio.f.mod.const
                            #, fs_ratio.f.des, fs_ratio.HH, fs_ratio.Frev,
fs_ratio.HHrev
                           )

FS.dataset        = data.frame(Ratio.fsecurity[1:26,])

setwd("M:\\My Documents\\Master thesis stuff\\R models\\Data files
output\\")
write.table(FS.dataset, file = "Foodsecurity_dataset.txt")
```

```
##### plots ####
par(mfrow=c(2,2))
currentFS    = Ratio.fsecurity[order(Ratio.fsecurity[,2]),]
barplot(currentFS[,2],names.arg=currentFS[,1], main ="Current food security
ratio", ylim = c(0,16),
        xlab = "Household number", ylab = "Food security ratio (-)")
abline(h = 1, col = "red", lwd = 2)

FSMOD.base    = Ratio.fsecurity[order(Ratio.fsecurity[,3]),]
barplot(FSMOD.base[,3],names.arg=FSMOD.base[,1], main =" Base modelled food
security ratio", ylim = c(0,16),
        xlab = "Household number", ylab = "Food security ratio (-)")
abline(h = 1, col = "red", lwd = 2)

FSMOD.const    = Ratio.fsecurity[order(Ratio.fsecurity[,5]),]
barplot(FSMOD.const[,5],names.arg=FSMOD.const[,1], main ="Constrained
modelled food security ratio", ylim = c(0,16),
        xlab = "Household number", ylab = "Food security ratio (-)")
abline(h = 1, col = "red", lwd = 2)

FSMOD.free    = Ratio.fsecurity[order(Ratio.fsecurity[,4]),]
barplot(FSMOD.free[,4],names.arg=FSMOD.free[,1], main ="Free modelled food
security ratio", ylim = c(0,16),
        xlab = "Household number", ylab = "Food security ratio (-)")
abline(h = 1, col = "red", lwd = 2)



plot.new()
par(mfrow= c(1,1))

HHCode.order2   = Farmers$HHCode[order(fs_ratio.f.mod.base)]
FS.base         = fs_ratio.f.mod.base[order(fs_ratio.f.mod.base)]

base.const.dif2 = fs_ratio.f.mod.const - fs_ratio.f.mod.base
base.const.dif2 = ifelse(base.const.dif2 < 0, 0,
base.const.dif2)[order(fs_ratio.f.mod.base)]
const.free.dif2 = fs_ratio.f.mod.free - ifelse(fs_ratio.f.mod.const == 0.0,
fs_ratio.f.mod.base, fs_ratio.f.mod.const)
const.free.dif2 = ifelse(const.free.dif2 < 0, 0,
const.free.dif2)[order(fs_ratio.f.mod.base)]
FSGRAPH         = cbind(HHCode.order, FS.base, base.const.dif2,
const.free.dif2)

barplot(t(FSGRAPH[,2:4]), names.arg = HHCode.order2, ylim = c(0,16), col =
c("deepskyblue", "dodgerblue2", "dodgerblue4"),
        xlab = "Household number", ylab = "Food security ratio (-)", axes =
F)
legend("topleft", fill = c("deepskyblue", "dodgerblue2", "dodgerblue4"), cex
= 0.8,
       legend = c("Base", "Constrained", "Free"), bty="n")
abline(h = 1, col = "red", lwd = 2)
axis(2, at = seq(0,16,2))
```

The Linear programming model

```
# install.packages("lpSolve")
# library("lpSolve")
########### data to be accessed #################
# Here the scripts for the LP model are run first. they contain the arious parameters and calculations for the parameters that
# are necessary for the model to run. the parameters are attached when the scripts are run thus names() are actually also useless
# however they might be handy just be sure of what's what.
# use the source() code, this makes it possible to run the desired scripts from this script here.

# setwd("M:\\My Documents\\Master thesis stuff\\R models\\")
# source("Land.estimation.model.R", echo = T)
# setwd("M:\\My Documents\\Master thesis stuff\\R models\\")
# source("Farmers model.R", echo = T)

#### Dataset ####

foodbasket       = read.delim("M:\\My Documents\\Master thesis stuff\\R models\\Data files input\\Text files\\food basket division.txt")

########### parameters ################

names(Farmers)
names(Land.per)
names(Farmers.area)

#### calculation ####

HH_energy_req          = Member.HH.from18 * 2400 * 365 + Member.HH.to18 * 1800 * 365

####### The model in words ######
# maximize (profit)

#### objective function ####
# income = - input costs - wage costs + sold - bought

# -(input costs (per ha) + wage costs (per ha)) * x1,x2,x3,x4,x5,x6 + crop price * x7,x9x,11,x13,x15 - crop price * x8,x10,x12,x14,x16
```

```
#### constraints ####

## land ##
# x1 + x2 + x3 + x4 + x5 + x6    <= max land
# x1 + x2                        <= 0.6 * max land
#         x3 + x4 + x5 + x6     <= 0.45 * max land
# x1                             >= 0.1 * max land
#             x4                 >= 0.05 * max land


## labour ##
# coffee_prod_lh * x1 + banana_prod_lh * x2 + maize_prod_lh * x3 + beans_prod_lh * x4 + cassava_prod_lh * x5 + other_prod_lh * x6

## food security ##
# yield - sold + bought = household energy requirement

# land productivity * x2,x3,x4,x5,x6 - x7,x9,x11,x13,x15 + x8,x10,x12,x14,x16 >= (((proportion of diet * household energy requirement)/ energy value per kg)/ edible content)

############# the basic dataframe ##########
```

The basic data frames are shown below in the tables to aid in the understanding of the script. The abbreviations are from the parameter calculation scripts. The first table show the values for the base scenario, the second for the constrained scenario and the last show the constraints for the free scenario.

base scenario	activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	right hand side
constraints	**objective**	(coffee_WSprice * coffee_prod_kg * cropcalories[9,5]) - (coffee_in_cost)	(- (banana_in_cost))	(- (maize_in_cost))	(- (beans_in_cost))	(- (cassava_in_cost))	(- (other_in_cost))	banana_Ws price	(- banana_RTprice)	maize_WSprice * cropcalories [1,8]	(- maize_RTprice)	beans_WSprice * cropcalories [5,8]	(- beans_RTprice)	cassava_Wsprice	(- cassava_RTprice)	other_WS price	(- other_RTprice)	0 # total labour	0 # family labour	- Farm.labour.cost	-
1		1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	max.area
2		coffee_prod_lh	banana_prod_lh	maize_prod_lh	beans_prod_lh	cassava_prod_lh	other_prod_lh	0	0	0	0	0	0	0	0	0	0	-1	0	0	0
3		0	banana_prod_kg	0	0	0	0	-1	1	0	0	0	0	0	0	0	0	0	0	0	0
4		0	0	maize_prod_kg	0	0	0	0	0	-1	1	0	0	0	0	0	0	0	0	0	0
5		0	0	0	beans_prod_kg	0	0	0	0	0	0	-1	1	0	0	0	0	0	0	0	0
6		0	0	0	0	cassava_prod_kg	0	0	0	0	0	0	0	-1	1	0	0	0	0	0	0
7		0	0	0	0	0	other_prod_kg	0	0	0	0	0	0	0	0	-1	1	0	0	0	0
8		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	coffee.area
9		0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	banana.area
10		0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	maize.area
11		0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	beans.area
12		0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	cassava.area
13		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	other.area
14		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	-1	0
15		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	farm.tota.labday
16		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	farm.family.labday
17		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

The constrained scenario constraints

constrained scenario	activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	right hand side
constraints	**objective**	(coffee_WSprice * coffee_prod_kg * cropcalories[9,5]) - (coffee_in_cost)	(-(banana_in_cost))	(-(maize_in_cost))	(-(beans_in_cost))	(-(cassava_in_cost))	(-(other_in_cost))	banana_Wsprice	(-banana_RTprice)	maize_WS price * cropcalories[1,8]	(-maize_RTprice)	beans_WS price * cropcalories[5,8]	(-beans_RTprice)	cassava_Wsprice	(-cassava_RTprice)	other_WS price	(-other_RTprice)	0 # total labour	0 # family labour	-Farm.labour.cost	-
1		1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	max.area
2		coffee_prod_lh	banana_prod_lh	maize_prod_lh	beans_prod_lh	cassava_prod_lh	other_prod_lh	0	0	0	0	0	0	0	0	0	0	-1	0	0	0
3		0	banana_prod_kg	0	0	0	0	-1	1	0	0	0	0	0	0	0	0	0	0	0	((foodbasket[1,3] * HH_energy_req) / banana_kcal_kg) / ((1 - cropcalories[3,6]) * cropcalories[3,7])
4		0	0	maize_prod_kg	0	0	0	0	0	-1	1	0	0	0	0	0	0	0	0	0	((foodbasket[2,3] * HH_energy_req) / maize_kcal_kg) / cropcalories[1,7]
5		0	0	0	beans_prod_kg	0	0	0	0	0	0	-1	1	0	0	0	0	0	0	0	((foodbasket[3,3] * HH_energy_req) / beans_kcal_kg) / cropcalories[5,7]
6		0	0	0	0	cassava_prod_kg	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	((foodbasket[4,3] * HH_energy_req) / cassava_kcal_kg) / cropcalories[7,7]
7		0	0	0	0	0	other_prod_kg	0	0	0	0	0	0	0	0	-1	1	0	0	0	((foodbasket[5,3] * HH_energy_req) / other_kcal_kg) / cropcalories[10,7]
8		1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	(((Per.Coffee + Per.Banana)+10)/100) * Max.area # perennials
9		0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	(((Per.Maize + Per.Beans + Per.Cassava + Per.Other)+10)/100) * Max.area # annuals
10		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	(min(Per.Coffee) / 100) * Max.area # coffee
11		0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	(min(Per.Beans) / 100) * Max.area # beans
12		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	-1	0
13		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	farm.tota.labday
14		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	farm.family.labday
15		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

The free scenario constraints.

free scenario	activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	right hand side
constraints	**objective**	(coffee_WSprice * coffee_prod_kg * cropcalories[9,5]) - (coffee_in_cost)	(- (banana_in_cost))	(- (maize_in_cost))	(- (beans_in_cost))	(- (cassava_in_cost))	(- (other_in_cost))	banana_Wsprice	(- banana_RTprice)	maize_WS price * cropcalories[1,8]	(- maize_RTprice)	beans_WS price * cropcalories[5,8]	(- beans_RTprice)	cassava_Wsprice	(- cassava_RTprice)	other_WS price	(- other_RTprice)	0 # total labour	0 # family labour	- Farm.labour.cost	-
1		1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	max.area
2		coffee_prod_lh	banana_prod_lh	maize_prod_lh	beans_prod_lh	cassava_prod_lh	other_prod_lh	0	0	0	0	0	0	0	0	0	0	-1	0	0	0
3		0	banana_prod_kg	0	0	0	0	-1	1	0	0	0	0	0	0	0	0	0	0	0	((foodbasket[1,3] * HH_energy_req) / banana_kcal_kg) / ((1 - cropcalories[3,6]) * cropcalories[3,7])
4		0	0	maize_prod_kg	0	0	0	0	0	-1	1	0	0	0	0	0	0	0	0	0	((foodbasket[2,3] * HH_energy_req) / maize_kcal_kg) / cropcalories[1,7]
5		0	0	0	beans_prod_kg	0	0	0	0	0	0	-1	1	0	0	0	0	0	0	0	((foodbasket[3,3] * HH_energy_req) / beans_kcal_kg) / cropcalories[5,7]
6		0	0	0	0	cassava_prod_kg	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	((foodbasket[4,3] * HH_energy_req) / cassava_kcal_kg) / cropcalories[7,7]
7		0	0	0	0	0	other_prod_kg	0	0	0	0	0	0	0	0	-1	1	0	0	0	((foodbasket[5,3] * HH_energy_req) / other_kcal_kg) / cropcalories[10,7]
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	-1	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
10		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	farm.family.labday
11		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

```
### data frames that have all the values for the LP model ####
# the values are specified above and can thus also be manipulated there #

objectives= data.frame(obj1, obj2, obj3, obj4, obj5, obj6, obj7, obj8, obj9, obj10, obj11, obj12, obj13, obj14, obj15, obj16 , obj17, obj18, obj19
                      )
constraint= data.frame(con1_1, con1_2, con1_3, con1_4, con1_5, con1_6, con1_7, con1_8, con1_9, con1_10, con1_11, con1_12, con1_13, con1_14,
con1_15, con1_16, con1_17, con1_18, con1_19, con2_1, con2_2, con2_3, con2_4, con2_5, con2_6, con2_7, con2_8, con2_9, con2_10, con2_11, con2_12,
con2_13, con2_14, con2_15, con2_16, con2_17, con2_18, con2_19, con3_1, con3_2, con3_3, con3_4, con3_5, con3_6, con3_7, con3_8, con3_9, con3_10,
con3_11, con3_12, con3_13, con3_14, con3_15, con3_16, con3_17, con3_18, con3_19, con4_1, con4_2, con4_3, con4_4, con4_5, con4_6, con4_7, con4_8,
con4_9, con4_10, con4_11, con4_12, con4_13, con4_14, con4_15, con4_16, con4_17, con4_18, con4_19, con5_1, con5_2, con5_3, con5_4, con5_5,
con5_6, con5_7, con5_8, con5_9, con5_10, con5_11, con5_12, con5_13, con5_14, con5_15, con5_16, con5_17, con5_18, con5_19, con6_1, con6_2,
con6_3, con6_4, con6_5, con6_6, con6_7, con6_8, con6_9, con6_10, con6_11, con6_12, con6_13, con6_14, con6_15, con6_16, con6_17, con6_18,
con6_19, con7_1, con7_2, con7_3, con7_4, con7_5, con7_6, con7_7, con7_8, con7_9, con7_10, con7_11, con7_12, con7_13, con7_14, con7_15, con7_16,
con7_17, con7_18, con7_19, con8_1, con8_2, con8_3, con8_4, con8_5, con8_6, con8_7, con8_8, con8_9, con8_10, con8_11, con8_12, con8_13, con8_14,
con8_15, con8_16, con8_17, con8_18, con8_19, con9_1, con9_2, con9_3, con9_4, con9_5, con9_6, con9_7, con9_8, con9_9, con9_10, con9_11, con9_12,
con9_13, con9_14, con9_15, con9_16, con9_17, con9_18, con9_19, con10_1, con10_2, con10_3, con10_4, con10_5, con10_6, con10_7, con10_8, con10_9,
con10_10, con10_11, con10_12, con10_13, con10_14, con10_15, con10_16, con10_17, con10_18, con10_19, con11_1, con11_2, con11_3, con11_4,
con11_5, con11_6, con11_7, con11_8, con11_9, con11_10, con11_11, con11_12, con11_13, con11_14, con11_15, con11_16, con11_17, con11_18,
con11_19, con12_1, con12_2, con12_3, con12_4, con12_5, con12_6, con12_7, con12_8, con12_9, con12_10, con12_11, con12_12, con12_13, con12_14,
con12_15, con12_16, con12_17, con12_18, con12_19, con13_1, con13_2, con13_3, con13_4, con13_5, con13_6, con13_7, con13_8, con13_9, con13_10,
con13_11, con13_12, con13_13, con13_14, con13_15, con13_16, con13_17, con13_18, con13_19, con14_1, con14_2, con14_3, con14_4, con14_5,
con14_6, con14_7, con14_8, con14_9, con14_10, con14_11, con14_12, con14_13, con14_14, con14_15, con14_16, con14_17, con14_18, con14_19,
con15_1, con15_2, con15_3, con15_4, con15_5, con15_6, con15_7, con15_8, con15_9, con15_10, con15_11, con15_12, con15_13, con15_14, con15_15,
con15_16, con15_17, con15_18, con15_19, con16_1, con16_2, con16_3, con16_4, con16_5, con16_6, con16_7, con16_8, con16_9, con16_10, con16_11,
con16_12, con16_13, con16_14, con16_15, con16_16, con16_17, con16_18, con16_19, con17_1, con17_2, con17_3, con17_4, con17_5, con17_6, con17_7,
con17_8, con17_9, con17_10, con17_11, con17_12, con17_13, con17_14, con17_15, con17_16, con17_17, con17_18, con17_19 )
righthand = data.frame(rhs1, rhs2, rhs3, rhs4, rhs5, rhs6, rhs7, rhs8, rhs9, rhs10, rhs11, rhs12, rhs13, rhs14, rhs15, rhs16, rhs17
                      )
directions= c("<=", "<=" ,">=", ">=", ">=", ">=", ">=" ,"=", "=", "=", "=", "=", "=" , "=", "=", "=" ,">=")

### vectors that are going to contain the data ####
income.vector    = c()
division.vector  = c()
```

```
shadowpri.vector = c()

### the model ####
# in objectives, constraints and right hand the parameters for the model are specified. each row is a farmer thus in the model below
# each row will be called upon to give values for each farmer and use them for the LP calculations, through a for loop.
# the first, income, calculates only results from the objective function, the income from the crops of the farmer.
# the second, division, shows the values that belong to each x, this shows the land division, labour division and how much kg the farmer sells and buys.
# the third, shadowpri, calculates the shadow prices of the x's and the right hand side values
# values of these calculations are saved in the three empty vectors specified above, which will be manipulated when the calculations are done.


for (i in 1:nrow(objectives)) {
  f.obj = as.matrix(objectives)[i,]
  f.con = matrix (c(as.matrix(constraint)[i,]), nrow=17, byrow=TRUE)
  f.dir = directions
  f.rhs = as.matrix(righthand)[i,]

  income   = lp ("max", f.obj, f.con, f.dir, f.rhs)$objval # show the income from the farm then
  division = lp ("max", f.obj, f.con, f.dir, f.rhs)$solution # shows the land allocation
  shadowpri= lp ("max", f.obj, f.con, f.dir, f.rhs, compute.sens=TRUE)$duals # the shadow prices of the RHS and constraints

  income.vector    = c(income.vector, income)
  division.vector  = c(division.vector, division)
  shadowpri.vector = c(shadowpri.vector, shadowpri)
}

income.vector
division.vector
shadowpri.vector
```

```
###### data cleanup and table making #######

divisionnames    = c("area.coffee", "area.banana", "area.maize", "area.beans", "area.cassava", "area.others", "sold.banana", "bought.banana", "sold.maize", "bought.maize", "sold.beans", "bought.beans"                ,"sold.cassava", "bought.cassava", "sold.other", "bought.other", "labour", "farmlab", "hiredlab")

shadowpricesnames = c("sh.land", "sh.labour", "sh.food.banana", "sh.food.maize","sh.food.beans", sh.food.cassava", "sh.food.others", "sh.land.coffee", "sh.land.banana", "sh.land.maize","sh.land.beans", "sh.land.cassava", "sh.land.other", "sh.tot.labour" , "labour.const", "sh.fam.labour", "sh.hired.labour", "sh.coffee.land", "sh.banana.land", "sh.maize.land", "sh.beans.land", "sh.cassava.land", "sh.others.land", "sh.banana.sold", "sh.banana.bought", "sh.maize.sold", "sh.maize.bought", "sh.beans.sold", "sh.beans.bought", "sh.cassava.sold", "sh.cassava.bought", "sh.other.sold", "sh.other.bought", "sh.labour", "sh.farmlab", "sh.hiredlab")

divisionx6      = split(division.vector, divisionnames)
shadowprix9      = split(shadowpri.vector, shadowpricesnames)

divisionland         = data.frame(divisionx6$area.coffee, divisionx6$area.banana, divisionx6$area.maize, divisionx6$area.beans, divisionx6$area.cassava, divisionx6$area.others, divisionx6$sold.banana, divisionx6$bought.banana, divisionx6$sold.maize, divisionx6$bought.maize, divisionx6$sold.beans, divisionx6$bought.beans, divisionx6$sold.cassava, divisionx6$bought.cassava, divisionx6$sold.other, divisionx6$bought.other, divisionx6$labour, divisionx6$farmlab , divisionx6$hiredlab)

shadowprices                    = data.frame(shadowprix9$sh.land, shadowprix9$sh.labour, shadowprix9$sh.food.banana, shadowprix9$sh.food.maize, shadowprix9$sh.food.beans, shadowprix9$sh.food.cassava, shadowprix9$sh.food.others, shadowprix9$sh.land.coffee, shadowprix9$sh.land.banana, shadowprix9$sh.land.maize, shadowprix9$sh.land.beans, shadowprix9$sh.land.cassava, shadowprix9$sh.land.other, shadowprix9$sh.tot.labour, shadowprix9$labour.const, shadowprix9$sh.fam.labour, shadowprix9$sh.hired.labour, shadowprix9$sh.coffee.land, shadowprix9$sh.banana.land, shadowprix9$sh.maize.land, shadowprix9$sh.beans.land, shadowprix9$sh.cassava.land, shadowprix9$sh.others.land, shadowprix9$sh.banana.sold, shadowprix9$sh.banana.bought, shadowprix9$sh.maize.sold, shadowprix9$sh.maize.bought, shadowprix9$sh.beans.sold, shadowprix9$sh.beans.bought, shadowprix9$sh.cassava.sold, shadowprix9$sh.cassava.bought, shadowprix9$sh.other.sold, shadowprix9$sh.other.bought, shadowprix9$sh.labour, shadowprix9$sh.farmlab, shadowprix9$sh.hiredlab)

combineddataset   = data.frame(HHCode, income.vector, divisionland, shadowprices)
```

```
names(combineddataset)[3:57] = c("area.coffee", "area.banana", "area.maize", "area.beans", "area.cassava", "area.others", "sold.banana", "bought.banana", "sold.maize", "bought.maize", "sold.beans", "bought.beans", "sold.cassava", "bought.cassava", "sold.other", "bought.other", "labour", "farmlab", "hiredlab", "sh.land", "sh.labour", "sh.food.banana", "sh.food.maize", "sh.food.beans", "sh.food.cassava", "sh.food.others", "sh.land.coffee", "sh.land.banana", "sh.land.maize","sh.land.beans", "sh.land.cassava", "sh.land.other", "sh.tot.labour", "labour.const","sh.fam.labour", "sh.hired.labour", "sh.coffee.land", "sh.banana.land", "sh.maize.land", "sh.beans.land", "sh.cassava.land", "sh.others.land", "sh.banana.sold", "sh.banana.bought", "sh.maize.sold", "sh.maize.bought", "sh.beans.sold", "sh.beans.bought", "sh.cassava.sold", "sh.cassava.bought", "sh.other.sold", "sh.other.bought", "sh.labour", "sh.farmlab", "sh.hiredlab")

setwd("M:\\My Documents\\Master thesis stuff\\R models\\Data files output\\Runs\\")
write.table(combineddataset, file = "base results.txt1", dec = ",")
write.table(combineddataset, file = "base results.txt", dec = ".")
write.csv(combineddataset, file = "base results.csv")
```

Table 20. Table with the value of the right hand side. The use in each scenario is indicated in the last row. (B) stands for base, (C) stands for constrained and (F) for the free scenario.

RHS category	Land											Labour		Food security				
Name	Max area	Coffee area	Banana area	Maize area	Beans area	Cassava area	Other area	Perennials	Annuals	Minimal coffee	Minimal beans	Farm total	Family total	Intake of banana	Intake of maize	Intake of beans	Intake of cassava	Intake of other
Unit	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(ha)	(labour day)	(labour day)	(kg)	(kg)	(kg)	(kg)	(kg)
1	2.30	0.58	0.69	0.46	0.23	0.23	0.12	1.50	1.27	0.35	0.12	221.93	207.21	3173.13	267.38	459.90	173.16	862.31
2	0.84	0.25	0.13	0.08	0.21	0.13	0.04	0.46	0.54	0.13	0.04	265.46	253.46	3,777.53	318.31	547.50	206.14	1,026.56
3	4.02	0.80	0.20	1.41	1.01	0.20	0.40	1.41	3.42	0.60	0.20	231.91	186.63	2,115.42	178.26	306.60	115.44	574.88
5	1.52	0.53	0.30	0.15	0.23	0.23	0.08	0.99	0.84	0.23	0.08	158.45	142.49	4,684.14	394.71	678.90	255.61	1,272.94
7	0.63	0.19	0.06	0.22	0.06	0.03	0.06	0.32	0.44	0.10	0.03	526.29	444.32	4,533.04	381.98	657.00	247.36	1,231.88
8	0.51	0.08	0.03	0.13	0.10	0.10	0.08	0.15	0.46	0.08	0.03	543.90	489.84	3,022.02	254.65	438.00	164.91	821.25
10	4.07	0.81	0.41	1.02	0.61	0.41	0.81	1.63	3.26	0.61	0.20	540.53	540.53	4,986.34	420.17	722.70	272.10	1,355.06
11	0.65	0.16	0.03	0.23	0.13	0.06	0.03	0.26	0.52	0.10	0.03	600.18	600.18	5,137.44	432.91	744.60	280.35	1,396.13
12	0.60	0.21	0.12	0.09	0.03	0.09	0.06	0.39	0.33	0.09	0.03	507.25	504.32	3,173.13	267.38	459.90	173.16	862.31
14	1.46	0.29	0.44	0.22	0.22	0.15	0.15	0.88	0.88	0.22	0.07	447.10	403.52	3,626.43	305.58	525.60	197.89	985.50
15	0.20	0.09	0.02	0.01	0.02	0.03	0.03	0.13	0.11	0.03	0.01	240.27	240.27	2,719.82	229.19	394.20	148.42	739.13
16	0.68	0.21	0.03	0.14	0.14	0.07	0.10	0.31	0.51	0.10	0.03	472.88	387.05	3,928.63	331.05	569.40	214.38	1,067.63
21	0.54	0.16	0.13	0.03	0.08	0.08	0.05	0.35	0.30	0.08	0.03	454.19	453.57	8,763.87	738.49	1,270.20	478.24	2,381.63
24	1.27	0.51	0.32	0.25	0.06	0.06	0.06	0.95	0.57	0.19	0.06	340.63	265.51	3,022.02	254.65	438.00	164.91	821.25
31	0.44	0.11	0.04	0.16	0.04	0.02	0.07	0.20	0.33	0.07	0.02	491.20	344.05	1,662.11	140.06	240.90	90.70	451.69
33	0.53	0.13	0.11	0.11	0.08	0.05	0.05	0.29	0.35	0.08	0.03	403.43	393.71	1,208.81	101.86	175.20	65.96	328.50
37	0.34	0.13	0.05	0.03	0.08	0.02	0.02	0.22	0.18	0.05	0.02	299.96	252.25	3,022.02	254.65	438.00	164.91	821.25
39	1.57	0.55	0.31	0.08	0.31	0.24	0.08	1.02	0.86	0.24	0.08	529.07	365.36	3,475.33	292.85	503.70	189.65	944.44
40	0.87	0.48	0.09	0.09	0.13	0.04	0.04	0.65	0.39	0.13	0.04	217.69	178.40	3,475.33	292.85	503.70	189.65	944.44
41	0.94	0.33	0.14	0.14	0.09	0.09	0.14	0.57	0.57	0.14	0.05	456.62	340.86	4,684.14	394.71	678.90	255.61	1,272.94
43	1.78	0.71	0.36	0.36	0.09	0.18	0.09	1.25	0.89	0.27	0.09	688.56	674.53	3,324.23	280.12	481.80	181.40	903.38
45	0.20	0.05	0.03	0.05	0.03	0.02	0.02	0.10	0.14	0.03	0.01	664.31	637.89	3,928.63	331.05	569.40	214.38	1,067.63
48	0.22	0.09	0.04	0.03	0.02	0.02	0.01	0.15	0.11	0.03	0.01	236.73	234.81	2,568.72	216.45	372.30	140.17	698.06
49	0.30	0.06	0.05	0.06	0.06	0.05	0.03	0.14	0.23	0.05	0.02	202.46	192.75	1,511.01	127.33	219.00	82.45	410.63
51	2.00	0.60	0.20	0.30	0.20	0.10	0.60	1.00	1.40	0.30	0.10	373.68	193.18	6,044.05	509.30	876.00	329.82	1,642.50
52	0.63	0.19	0.06	0.09	0.16	0.03	0.09	0.31	0.44	0.09	0.03	466.27	308.59	1,208.81	101.86	175.20	65.96	328.50
Scenario	B, C, F	B	B	B	B	B	B	C	C	C	C	B, C	B, C, F	C, F	C, F	C, F	C, F	C, F