Understanding the role of soybean (*Glycine max* (L.) Merrill) cultivation by smallholder farmers in northern Uganda

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Abstract

With an increasing population, food production also needs to increase in Uganda. However, continuous crop cultivation and a low use of external inputs is expected to cause nutrient depletion resulting in diminishing crop yields. Nitrogen is an important nutrient for crop growth and is commonly limiting agricultural production. Leguminous crops have the ability to fix nitrogen from the atmosphere in a symbiotic relationship with rhizobia (bacteria) in the soil. In Oyam, a district in northern Uganda, the N2Africa project disseminated cultivation technologies for soybean, such a leguminous crop. It was unclear how the crop was performing in this region and whether the disseminated technologies were used. The aim of this research was to understand the role of soybean in smallholder farm households and how the disseminated cultivation technologies (improved varieties, inoculants, P-fertilizer) were used in variable farm systems. To understand the diversity of farmer households, a rapid farm characterization was done using three focus group discussions. Afterwards, a more detailed household survey and field survey were done with 20 selected households in the first growing season of 2018. The farmers were divided in three categories based on their farm size and livestock ownership: large area – medium livestock (LA-ML) farmers, medium area – high livestock (MA-HL) farmers and small area – low livestock (SA-LL) farmers. Soybean was cultivated on 41% of the total farmland in the first season of 2018, and was therefore the crop cultivated by most farmers in this season. Farmers of all types allocated various proportions of land to soybean, and SA-LL farmers never allocated more than 55% while MA-HL and LA-ML farmers allocated up to almost 100%. Soils of MA-HL farmers were poorer than the soils of the other farmers in terms of nitrogen and organic carbon. There was no difference between soil characteristics between fields to which soybean was allocated. Farmers did not use any chemical fertilizer, manure or inoculants on soybean, and the use of biocides was very minimal on soybean. The use of improved soybean varieties was common for LA-ML and MA-HL farmers. Fields with soybean as main crop required more labour than the other fields where mainly cereals, cassava, sunflower and other legumes were cultivated. There were no differences between farm types in the percentage of nitrogen derived from biological nitrogen fixation, or the amount of N-fixed. However, in soybean the fixation was not sufficient to prevent nutrient depletion without the use of external inputs, considering an outflow through grain harvest of around 80 kg N ha^{-1} and an average fixation of 9.1 kg N ha^{-1}. The average soybean yield was 1695 kg ha^{-1}, with the highest on fields of SA-LL farmers (median yield of over 2000 kg ha^{-1}). There were sufficient markets for selling soybean, in which farm cooperatives played a large role. The share of soybean in household income was diverse (17-100% for LA-ML farmers, 0-93% for MA-HL farmers and 0-79% for SA-LL farmers). Farmers cultivated soybean mostly because of its high income potential, consumed little and were positive about cultivating and selling the crop. Soybean cultivation has been beneficial for farmers in Oyam, and the N_2Africa project seemed to have increased these benefits although the technologies disseminated by N_2Africa were not fully put into use. The imminent problem of nutrient depletion is not likely to be solved with the currently used soybean cultivation methods, but there is plenty of space left for improvements in the future.

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1. Introduction

1.1. Background

1.1.1. Agriculture in sub-Saharan Africa and Uganda

Uganda is a densely populated country with a population of almost 40 million inhabitants and high population growth rate of 3.2% in 2017 (CIA, 2017). With an increasing population, food production also needs an increase: sub-Saharan Africa is one of the regions where the human population increases faster than food production (van Ittersum *et al.*, 2016), food insecurity is therefore a major concern. With about 80% of the total employment in Uganda depending on agriculture and 71.2% of the country's land surface consisting of agricultural land (World Factbook, 2011), the agricultural sector is of great importance for the country. Depletion of natural capital stocks, especially soil fertility, is problematic in rural Uganda (Pender *et al.*, 2001). Current farm management is usually not preventing this. Continuous crop cultivation and low use of external inputs cause soil erosion and nutrient depletion, resulting in diminishing crop yields (Nkonya *et al.*, 2005). Sustainable agriculture requires that all nutrients taken up by crop cultivation or lost from the system, must be replenished. This is currently not the case in Uganda, the integration of livestock with crop production can contribute to improvements in soil fertility through the use of manure, although this alone may not adequately replenish the soil (Pender *et al.*, 2001). Pender *et al.* (2001) estimated that less than 10% of the smallholder farmers in Uganda apply inorganic fertilizer. Nitrogen is one of the nutrients required in the largest quantities for plant growth, and one which is commonly limiting for agricultural production. For nitrogen, however, there is an alternative to restore supplies: it can be directly captured, 'fixed', from the atmosphere by legumes (Giller, 2001). This principle is widely used in agricultural production, also by farmers in Uganda. Uganda's agriculture is characterized by smallholder farming. Smallholder farming systems in sub-Saharan Africa, and also in Uganda, exist within diverse biophysical and socio-economic environments. Even within localities and villages, farm households differ in resource endowment, production orientation, soil fertility status, cash income, livestock ownership, labour availability and many other aspects. All characteristics of a farm household determine decisions they take in their farm management, and therefore also whether they adopt certain (legume) technologies. Not all farmers benefit evenly from agricultural development activities (Tittonell *et al.*, 2010). Efforts should be focussed on understanding the socio-economic and biophysical variables of farm systems, as well as processes and interactions. However, it is unrealistic to develop unique recommendations for each household, and therefore strategies have to be developed to capture diversity and categorize farmers to develop appropriate recommendations.

1.1.2. Legumes and biological nitrogen fixation

Legumes, belonging to the family Leguminosae or Fabaceae, have the ability to fix atmospheric nitrogen (N_2) in a symbiotic relationship with rhizobia (bacteria) in the soil. The rhizobia infect the roots of the legumes and form nodules, where the N_2 is reduced to a biologically useful, combined form of N – ammonia – which plants can use (Giller, 2001). Provided that a legume crop is abundantly nodulated and effectively fixing N_2, large benefits in terms of N_2 fixation and crop production can be derived: up to 277 kg shoot N ha^{-1} was fixed by soybean in Africa (Peoples *et al.*, 2009). Nitrogen fixation does not work optimally in all circumstances and requires a basic soil fertility. However, keeping in mind the currently low yields and low fertilizer inputs, nitrogen fixation can be of large impact in Uganda. When securing the right conditions, soil fertility can be improved by the use of legumes, and also rotational benefits of grain legumes on cereal yields were reported (Franke *et al.*, 2018). Soybean (*Glycine max* (L.) Merrill), a nitrogen fixing Leguminosae, has a high potential within the cropping systems in Uganda. Soybean has the highest protein content and the highest gross output of vegetable oil among all cultivated crops in the world (Qiu and Chang, 2010), excepting palm oil. Besides it is widely used as animal feed and used in many processed food and non-food products (Hartman *et al.*, 2011). The origin of soybean cultivation lies in China, but the crop was introduced to Africa in the beginning of the 20th century (Khojely *et al.*, 2018). The cultivated area under soybean in Africa compared to the rest of the world is small, occupying 1.3% of the total world area representing 0.6% of the total world production. Uganda has a share of 8.5% in this total African production (FAOSTAT, 2013) and is the leading producer of soybean in eastern Africa. The global demand for soybean is increasing, and also in sub-Saharan Africa where the demand outweighs the production, imports from other continents are increasing (Murithi *et al.*, 2016). However, Uganda has already established its export market of soybean to neighbouring countries (Abate *et al.*, 2012). Besides the upcoming market, soybean has a good nutritious value. With a protein content of approximately 40%, soybean can be a good addition to any low-protein diet. To fill the gap between demand and supply of food, especially protein, growing soybean in sub-Saharan Africa can be a contribution (Hartman *et al.*, 2011). Unfortunately, soybean cultivation knows abiotic and biotic constraints, among which soybean rust poses a serious threat (Murithi *et al.*, 2016).

Soybean is efficient in biological nitrogen fixation in association with Bradyrhizobium in root nodules compared to other rhizobial strains, and thereby requires low nitrogen supplies in the form of chemical fertilizer for meeting its own nitrogen requirement if infected. The amount of nitrogen fixed is variable and depends on e.g. climatic conditions experienced during the growing period, soil conditions, agronomic practices and genotype. Soybean varieties can be of a determinate or a promiscuous nature: a promiscuous variety can nodulate with a wide variety of rhizobial strains, whereas a determinate variety needs a more specific strain. The more determinate varieties respond better to inoculants (van Heerwaarden *et al.*, 2018), but they are also more dependent on inoculants which can be problematic since local availability of quality inoculants is still a problem in Africa (Ronner *et al.*, 2016). Promiscuous varieties can nodulate with several introduced and indigenous strains, and still inoculation can positively influence yield response (Ronner *et al.*, 2016, van Heerwaarden *et al.*, 2018).

1.1.3. Preceding activities by the N_2Africa project

N_2Africa is a large-scale project that aims at putting nitrogen fixation to work for smallholder farmers in sub-Saharan Africa (N_2Africa – www.n2africa.org). The project focusses on increasing production of grain legumes and the inputs from N_2-fixation in smallholder farming systems. The focus is on four major grain legumes: common beans, cowpea, groundnut and soybean. Besides Uganda, many other countries are involved: Democratic Republic of Congo (DRC), Ghana, Kenya, Malawi, Mozambique, Nigeria, Rwanda, Zimbabwe, Ethiopia and Tanzania (Giller *et al.*, 2013).

This study focussed on the N_2Africa project in the northern region of Uganda, and specifically on the district of Oyam. In 2014, a baseline survey was done by N_2Africa in Oyam to provide a benchmark against which the progress and achievements of the project could be assessed (Stadler *et al.*, 2016). Subsequently, the N_2Africa project disseminated legume technologies in collaboration with World Vision Uganda (WVU) and the Agency for Sustainable Rural Transformation (AFSRT) aimed at creating awareness and capacity building. The technologies were disseminated mainly through demonstration, field days and adaptation trials. The demonstration and adaptation trials were conducted with farmer producer groups and cooperatives. On the demonstration plots, farmers could learn about improved soybean varieties (Maksoy 4N and 5N) and response to inoculation (Makbiofixer) alone or in combination with phosphorus fertilizer (TSP). Small packets with soybean seeds, inoculants and sometimes also TSP fertilizer were given to individual farmers to establish adaptation trials on their own farm and compare the performance with the demonstration plots and the local soybean varieties (Adjei-Nsiah *et al.*, 2014). The yield, performance and technologies of the demonstration plots and adaptation trials were evaluated at the end of the season by the farmers and researchers (Ampadu-Boakye *et al.*, 2018). In addition, AFSRT and N_2Africa put efforts in improving market access of local farmer cooperatives (Oyam Agro in Acaba, Bedijo in Minakulu and Loro Noteenteko Cooperative in Loro) and for those cooperatives input shops were facilitated (N_2Africa, 2017). Together with the Integrated Seed Sector Development (ISSD), N_2Africa trained farmers to produce quality seed of superior varieties for sale to other farmers in the region: local seed businesses (LSBs). WVU coordinated the development of five LSBs, organised with the cooperatives.

1.2. Research aim and research questions

The objective of this study was to understand the role of soybean cultivation in farm systems of different smallholders in Oyam, in relation to the practices related to soybean cultivation disseminated through N_2Africa (given in 1.1.3).

Main research question:

"What is the role of soybean cultivation in the farm systems of different smallholder farmers in Oyam?"

Sub- questions:

1. In which aspects do smallholder farms differ from each other and how can they be categorized into farm types?
2. What proportion of land is allocated to soybean cultivation?
3. What is the role of livestock?
4. What are differences in soil characteristics between fields to which soybean or non-legume crops are allocated?
5. Which cultivation techniques and inputs are used for soybean cultivation compared to other crops?
6. How much nitrogen is fixed by biological nitrogen fixation in soybean? Did variety play a role?
7. How do soybeans yield and how does this compare to other yields?
8. What is the share of soybean cultivation in household income?
9. What do farmers think about soybean cultivation?

2. Methodology

2.1. Research location

The research was conducted in Oyam, a district in the northern region of Uganda. Within Oyam, research locations were in the sub-counties Loro (Alidi village), Minakulu (Alati village), Acaba (Otulatum village), Oyam Town Council (Agoa village) and Otwal (Apito Lwak and Odolio Long village) (Figure 1).

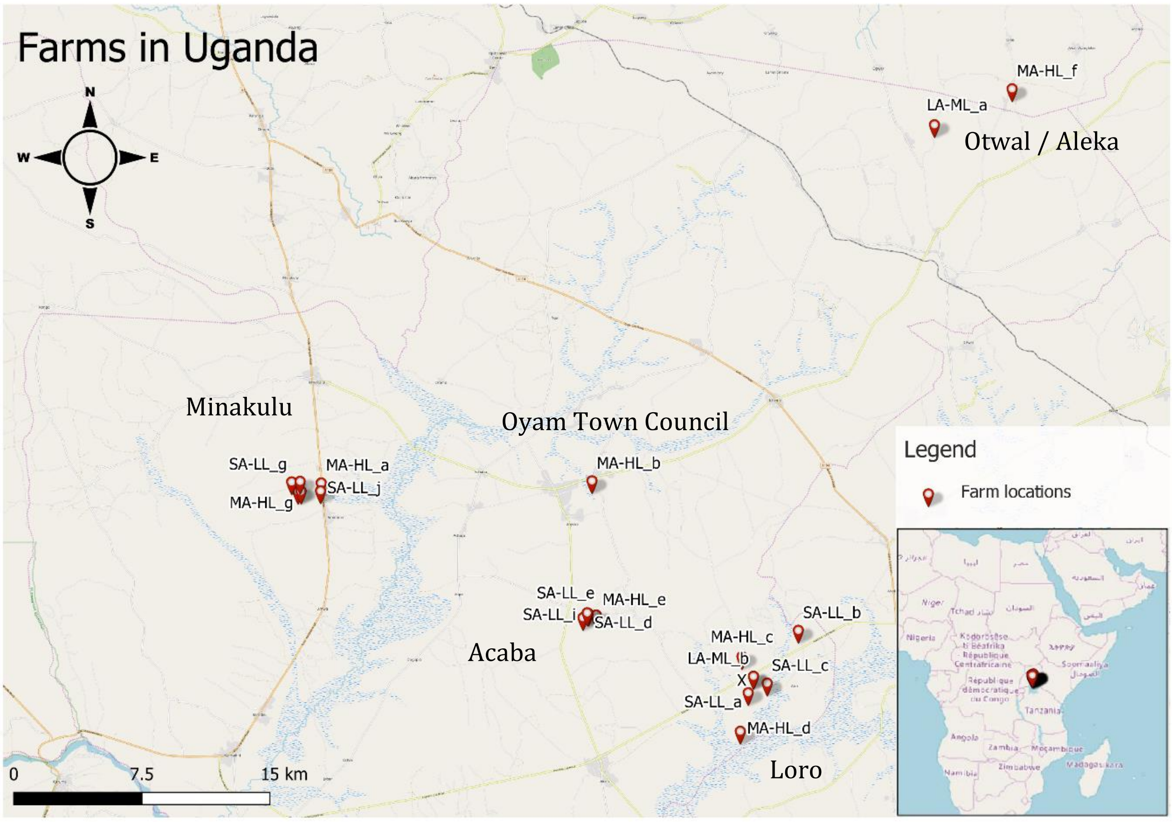

Figure 1. Map of Oyam with the location of the homesteads.

Oyam is a relatively new district, established in 2006 by the Ugandan Parliament. Before that, the area belonged to Apac district. Oyam is part of the larger Lango sub-region, and the dominant ethnic group are the Lango. The districts' natural resources include fertile arable soils, water bodies, rivers, forests and spring water. The soils are mainly of a ferralitic type (sandy sediments and sandy loam) (UBOS, 2013). The area is well known for its unique swamplands (the blue areas in Figure 1). Oyam has wet and dry seasons. The first rainfall peak is in April-May and the second is in August-October. The main dry season is from December until March and there is a drier period in June and July. The length of the growing period is around 255 days (van Velthuizen *et al.*, 2007), split into two growing seasons. The first is from March until July, the second is from August until December. This is corresponding with the rainy seasons, with most rain falling in the crop development stage. Average annual rainfall varies between 1200 and 1600 (UBOS, 2013). The average annual temperature is 22.5°C – 25.0°C (Hijmans *et al.*, 2005). Actual rainfall of season 2018A is given in Appendix XII). Cropping activities are the main source of income for around 85% of the households in Oyam (Stadler *et al.*, 2016). The main cultivated crops are maize, sunflower, soybean, sesame, common bean, cassava, cotton, pea, sorghum and millet. Most households own some livestock: mainly cattle, goats and poultry (Stadler *et al.*, 2016).

2.2. Main research approach

The first part of the research consisted of focus group discussions, which provided a rapid farm characterization as a basis for the household selection for the detailed farm characterization. The detailed farm characterization existed of several on-farm research activities, some of which involved sampling. An overview of the activities is given in Figure 2.

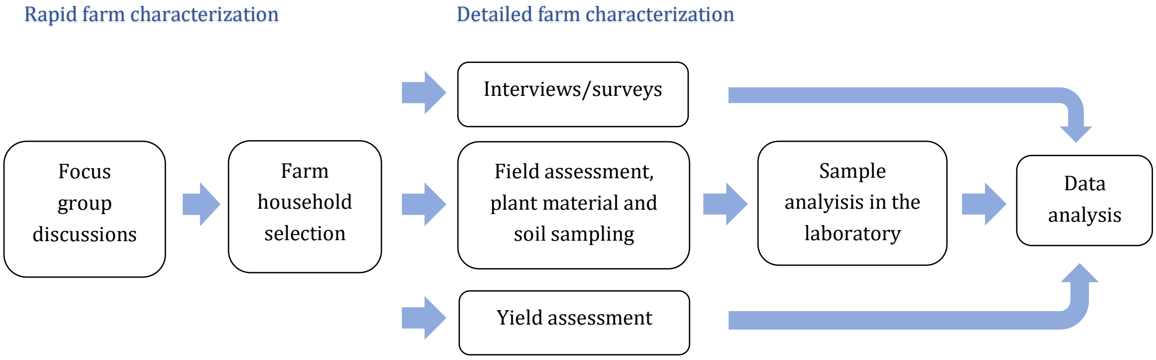

Figure 2. An overview of the steps taken from the beginning (left) until the end (right).

2.3. Rapid farm characterization

2.3.1. Focus group discussions

In the three core sub-counties Loro, Minakulu and Acaba, focus group discussions (FGDs) were held. The purpose of those FGDs was to gain information about the farmers and their farming activities, to understand differences between farmers in the area, and together with the farmers shape farm categories to base the farm selection on for the further research. The FGDs were done together with a fellow student and were also a part of his thesis research. Translation was facilitated by the field assistant when necessary.

All three FGDs had 10 participants. The groups consisted of farmers from the local farmer cooperative, approximately half of them were men and half of them were women. The FGDs were split up in three parts. In the first part (20-30 minutes), questions were asked about the farming activities in their subcounty in general and they were encouraged to speak about their crops, farm and the farmer cooperative. In the second part (45 minutes), the groups were split in two. In Acaba and Minakulu this was done randomly by numbering. In Loro, which was the third FGD, the group was split up based on gender. This was done because the first two FGDs were dominated by men and it seemed to be a good way to encourage the women to speak up more. In the smaller groups, the participants were asked to divide the farmers of their subcounty into categories, and to name the most important characteristics of those categories. In the third part (20 minutes), the groups reunited and the subgroups presented their findings to the others. The differences between the categorizations of both groups led to discussions and the participants were asked to combine both categorizations into one.

2.3.2. Farm categories

A farm categorization with four farm types was constructed with the information from the FGDs. It was cross-checked with several informants in the area: the Agricultural Officer and Commercial Officer of Oyam District, and a representative of the Agency for Sustainable Rural Transformation (AFSRT) with whom interviews were done. All informants generally agreed with the outcomes of the FGDs. The final categorization used for the farm household selection is given in Table 1 and a description of the types is given in Appendix I.

Table 1. The final categorization used for the household selection as constructed after the FGDs and stakeholder verification.

Farmer type	Production orientation	Land size	Tool use	Seed use	Farming knowledge	Labour	Input use[2]
1	Market	>10 acres	Tractor or ox plough	Improved seeds	Trained	Always hiring labour	Yes
2	Market > consumption	5-10 acres	Sometimes access to ox plough	Improved seeds > home seeds	Trained	Sometimes hiring labour	Sometimes
3	Consumption > market	2-5 acres	Sometimes access to ox plough	Home seeds[1] > improved seeds	Sometimes trained	Not hiring labour	Sometimes
4	Subsistence	<2 acres	Hand hoe (never ox plough)	Home seeds	Not trained	Not hiring labour	None

[1] This can also be improved seeds that are used for many seasons

[2] Inputs such as inoculants, fertilizer and pesticides

2.3.3. Household selection

Farm households were selected in three villages in sub-counties Loro, Minakulu and Acaba. The targeted villages were randomly selected villages close to the N_2Africa-influenced farmer cooperatives and trial locations (see paragraph 1.1.3) informed by the field assistant, who was involved in earlier activities of the N_2Africa project.

Because there was no information available about the farmers in the targeted villages, the village heads were asked to provide a list with the characteristics that the farm categories were based on: production orientation, farm size, access to ox plough, seed type use, farming training level, labour use and use of other inputs on the field. The village heads provided a list containing information of about 40 farmers in their village.

Not all farmers on the list matched one of the types as described in Table 1 on all characteristics. Therefore, a selection was made of farmers that matched most characteristics and from this selection five farmers per category, distributed approximately evenly over the three sub-counties, were randomly selected. This was done because a fully random selection would have led to a less diverse sample of farmers. Not enough farmers with large land areas could be found in the three villages. They were actively searched for, and three were found via contacts of the field assistant. One was found close to Acaba, in Oyam Town Council sub-county. The other two were found in Aleka, Otwal sub-county, unfortunately further away from the location of most N_2Africa activities but matching the category description. In total, 20 farmers were selected for the detailed farm characterization. All farmers cultivated soybean in 2017 or 2018.

2.4. Detailed farm characterization

The detailed farm characterization was done in three visits to the farm household. The first visit was a household survey with the farmer, the second a field survey and field assessment including soil and biomass sampling, and the third visit was at the end of the season to assess the harvest. All of these activities were assisted by a translator.

2.4.1. Household survey

The interview was the first acquaintance with the farmer and farm household. The survey was done with the household head and/or a spouse if involved in the farm management. First, basic information about the farm and farm household was asked, as well as information about income sources, production orientation, available resources, market access and product prices, crop production, livestock ownership and production activities. Besides the structured questionnaire, a casual conversation was held about soybean cultivation, N_2Africa and improved cultivation methods to gauge their thoughts about this. An overview of the topics discussed is given in Table 2, and the full survey is given in Appendix XIV.

2.4.2. Field phase

In the field, the field was discussed with the farmer. The farmer indicated his/her perception of soil fertility, the last fallow period of the field, the land preparation methods used in the second season of 2017 (from now on referred to as season 2017B) and the first season of 2018 (from now on referred to as season 2018A), the inputs (fertilizer, manure, biocides and inoculants) used in season 2017B and 2018A, the crops grown in the first season of 2017 (2017A) and season 2017B, the residue management, the distance from the field to the homestead, typical problems on the field, whether the field was owned or rented, and what crop variety was used (if known). Also, a labour calendar was filled in with the farmer, indicating how many man-days were spent on the field for land preparation, sowing and weeding, and whether this was hired or family labour. Furthermore, farmers indicated for what labour activities they used an ox plough.

Table 2. Topics discussed with the farmer in the household survey and in the field survey. The field survey was done on all fields of a farmer.

Household survey	**Field survey**
Household composition	Fertility estimate
Education level	Land ownership
Production orientation	Crops in season 2017A and 2017B
Income sources	Land preparation (2017B and 2018A)
Food security	Varieties used (2017B and 2018A)
N_2Africa involvement	Biocide, manure, inoculants and fertilizers use (2017B and 2018A)
Farmer cooperative	Residue management (2017B and 2018A)
Market access	Agronomic problems (2018A)
Farm size and land use	Cropping calendar and labour inputs per activity
Input and tool use	
Importance of crops	
Market prices	
Soybean conversation	
Livestock ownership	
Livestock inputs and sale	
Manure management	

Fields were identified, and the size was measured with a GPS. Whenever the field was smaller than 20 x 20 meters, the size of the field was measured with a tape measure. Also elevation was recorded with the GPS device. Slope, irregularities and visible erosion were estimated by eye. All crops on the field were identified. In case intercropping was done on the field, the percentage of area covered by a crop was estimated by eye. Furthermore, the planting distance of all crops on the field was measured with a tape measure on several locations in the field and subsequently a rough estimation was made for the entire field. When seeds were 'broadcasted' over the field, no planting distance was registered. Since the farmers regularly sowed more than one seed per hole, an estimation was made of the amount of plants growing from the same sowing hole by counting the amount of plants per sowing hole on several locations in the field.

The main soybean field, based on the perception of the farmer, was selected for soybean biomass sampling. The five farmers that did not grow soybean in season 2018A were excluded from this part of the research. For two other farmers, the field was not ready when the sampling time was scheduled. The biomass sampling for the remaining 13 took place in May-June, halfway the growing season. It started when the fields were at a 50% flowering stage, with the maximum amount of biomass present in the field. The sampling was done on representative, based on observation, two m^2 in the soybean field. All plants within this area were removed by cutting the stem at soil level. The plants were counted, and the aboveground weight was determined. Additionally, a subsample of 100 grams mixed shoot parts was taken.

After this, the roots were carefully dug up, and a nodulation scoring was done on 10 representative soybean roots to classify the presence of rhizobium nodules using the scheme in Figure 3. A few random nodules were opened to see whether the nodules were active. A pink-red interior indicates active nitrogen fixation (Bala *et al.*, 2010).

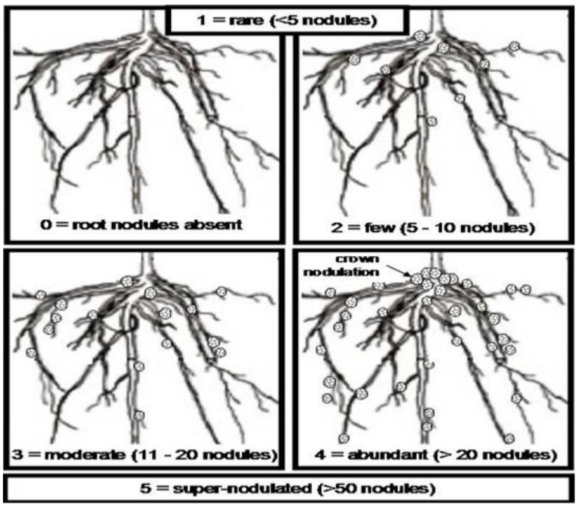

Figure 3. Root nodule classification system. From: Bala et al., 2010.

For the determination of nitrogen fixation by the leguminous plant, a non-fixing reference sample was used (further explanation is given in 2.4.5). The reference sample was composed of five different broad-leafed weeds collected from the soybean field, with approximately the same age as the soybean crop. From all five reference weeds, roughly even amounts were put in the subsample of around 100 grams, with roughly even amounts of shoot parts.

The soil sampling was done on the best and worst performing field of the farmer (according to the farmer) and on the field(s) on which soybean was grown in the current and/or previous season. This resulted in up to four sampled fields per farm. The goal was to capture as much variability in soil fertility as possible. Soil samples were taken of the top layer of the soil (0-20 cm) with a hand hoe (a tool for working the field) at eight to twelve random points in the field (depending on the field size), excepting points of discontinuity such as spots with many rocks. These samples were mixed thoroughly in a large bucket and combined into a composite sample. Of the composite sample, a subsample of 300 grams was taken.

2.4.3. Harvest

At the end of the growing season, all crops were harvested from an area of 100 m2 and in some cases 200 m2. The total fresh weight of the grains and stovers was recorded for every crop. Pea and cassava were not ready for harvest and were therefore left in the field. Some maize was not physiologically ready to harvest at the time of the harvest assessment and was left in the field, while parts were harvested. Unfortunately it was unknown how much maize was exactly left in the field.

2.5. Data analysis

2.5.1. Typology development

After the detailed farm characterization, it became clear that the typology used for the household selection could not be used anymore, because there were too many inconsistencies (see Appendix II for an overview). Many farm characteristics used in the first typology were different than initially thought, due to incorrect information on the lists of the village heads and contradicting findings in the detailed farm characterization. A frequent misunderstanding was about the measuring units of land size: some fields sizes were communicated using a local stick-length unit. Therefore, a new typology had to be constructed with farm characteristics from the detailed farm characterization.

Differences between farm types had to be quantified in some cases to calculate averages for the farm types (Table 3). Many farmers indicated that they were a member of a different farmer cooperative than the cooperatives targeted by N_2Africa, for example saving groups or labour sharing groups. These groups were not taken into account in the data analysis.

Table 3. Quantification of the responses received in the household survey.

Characteristic		Quantification
Production orientation	Only for the market	100%
	For both market and home consumption	50%
	For home consumption	0%
Improved seed use	All improved seeds	100%
	More improved seeds	75%
	Both improved and local seeds	50%
	Local seeds only	0%
Use of hired labour	Always hired	100%
	Hired sometimes	50%
	Never hired	0%
Input use	Used sometimes	50%
	Never used	0%
Education level	Illiterate	Scored 0
	Primary school	Scored 1
	Secondary school	Scored 2
	Higher education	Scored 3

Tropical Livestock Unit

The ownership of livestock was given in Tropical Livestock Unit (TLU). The TLU is calculated as the sum of all livestock of a type multiplied with a relative weight for that type of livestock. The relative weights used can be found in Appendix III. Ducks and doves are handled as poultry.

2.5.2. Intercropping

On fields with intercropping, the field size was multiplied with the percentage land covered with that crop to calculate the cultivated area. The total area of land per crop per farm household is calculated by adding up the areas of all fields.

The intercropping percentages were also used to calculate the yield per hectare. However, the use of the intercropping percentages based on visual estimation led to problematic overestimations of yield when it was grown in small percentages of the field (Appendix IV). This problem was most relevant for bean and maize yields, so that yields above respectively 4 t ha^{-1} and 10 t ha^{-1} were excluded because yields that were higher were only found at small intercropping percentages. Also one outlier in groundnut yield was excluded from the research. For all other yield data, the values corrected for intercropping were used. For all yield data, the dry weight is calculated using the grain moisture content data given in Appendix V.

2.5.3. Soil sample analysis

For financial reasons, not all samples could be analysed and a sub-selection was made. The samples from the largest owned fields of at least two farmers in each sub-county were selected, with samples from at least two farmers of every farm type. This was done to capture as much variety in location and farm types as possible. The soil samples were airdried and analysed in the laboratory of Yara Analytical Services in the United Kingdom. Here, the soil samples were analysed on organic matter (DUMAS), total nitrogen (Kjeldahl), pH (H_2O), phosphorus (Olsen), cation exchange capacity (CEC) (extraction with ammonium acetate), exchangeable cations potassium (Flame emission spectrometry), calcium, magnesium (atomic absorption spectrophotometry) and soil particle size (laser diffraction).

2.5.4. Biological nitrogen fixation

The soybean and reference samples were airdried in Uganda, and transported to the Netherlands. In the laboratory of Wageningen University they were oven-dried for 48 hours and grinded. The first grinding was coarse, the second grinding was done with a ball-mill to prepare the samples for the laboratory analysis at KU Leuven where the samples were analysed on %N and $\delta^{15}N$. Some samples had to be excluded from further use because they contained too much mould.

Enrichment of soil N occurs due to isotopic discrimination during processes such as ammonia volatilization, denitrification and other transformations of N in soil. As the ^{15}N isotope is heavier than ^{14}N, compounds containing ^{15}N tend to react more slowly, particularly in reactions that lead to gaseous losses from the soil. The net effect is that the soil, over long periods of time, becomes slightly enriched with ^{15}N.

Figure 4. Side note on soil enrichment with 15N. From Giller, 2001.

To measure the amount of nitrogen fixed by a plant, the natural abundance method according to Unkovich *et al*. (2008) and Peoples *et al.* (1989) was used. The technique is based on the principle that many soils are naturally enriched with ^{15}N (Figure 4) compared with the atmosphere, including many soils in the tropics (Giller, 2001). The nitrogen derived from N_2 fixation (%Ndfa) was calculated using equation 1 of Unkovich *et al.*, 2008.

$$\%\ \text{Ndfa} = [(\delta^{15}\text{N}_{\text{reference plant}} - \delta^{15}\text{N}_{\text{fixing plant}}) \div (\delta^{15}\text{N}_{\text{reference plant}} - \text{B})] \times 100 \qquad (1)$$

The 'B' value is the $\delta^{15}N$ of the same N_2 fixing plant when grown with N_2 as the sole source of N. Ideally, 'B' values should be prepared for each new species and rhizobial strain under study. In this study, a 'B' value from literature is used. Unkovich *et al*. (2008) suggest to use a mean of previously published 'B' values when the $\delta^{15}N$ of the reference plant is larger than 4‰ and the $\delta^{15}N$ of the legume is not less than the available 'B' value. An average 'B' value of -1.83 was chosen which is an average of several studies done with soybean across the world (Unkovich *et al.*, 2008). Belowground N contributions of legumes were not considered in this study.

The nitrogen fixed per hectare was calculated by taking the percentage fixed by biological nitrogen fixation of the percentage N in the soybean plant, multiplied with the dry soybean weight per hectare. The fresh soybean weight per hectare was derived from the soybean biomass on the two squared meters that were sampled. A dry matter content of the soybean shoot of 91% (Kermah *et al.*, 2018) was used to convert the fresh weight into dry weight, because an oven to properly dry the samples in was absent. From five fields, the reference weed samples were rotten before they reached the laboratory. An average of the other eight weed samples from the other eight fields was used for those fields instead.

2.5.5. Economic evaluation

The amount of seeds used per hectare was estimated using the amount of plants per hectare estimation based on the planting distance and the plants per sowing hole. The fact that not all seeds germinate was considered not highly influential for the seed price calculation. For sorghum, millet and sesame, the amount of plants per hectare was unknown and therefore the seed requirement was derived from other sources (Appendix VI). The seed weight needed was then calculated by the amount of seeds needed, divided by the number of seeds per gram which is found in literature (Appendix VI). The seed cost per hectare was calculated with the average seed price information given by the farmers (Appendix VII). Some farmers gave a seed or grain price for a cup: for all those cases the assumption was made that a kilogram contains 2.5 cups, based on local sources.

The gross margin from a field was calculated by multiplying the yield with the average grain price per unit yield for all crops and then subtracting the input costs. For cassava, which was not harvested in the end of the first season, an average yield of 14.4 t/ha (FAO, 2007) was used, divided by two because the crop grew for a full year and this calculation was for the season. Pea was longer on the field than the other crops and not harvested in July. Therefore, an estimated average crop harvest of 400 kg per hectare was used for pea (Omongo *et al*., 1998). For the missing harvest data or data that were unrealistically high, median crop yields of the farmers with harvest data were used of maize, bean, soybean and groundnut. Banana and local vegetable were not included in the calculation, because too little information about their harvest and prices was available and they were cultivated only on a small scale. Grain prices were based on average prices given by the farmers (Appendix VIII). The seed and grain price of millet was not given by the farmers and was therefore estimated to be around 0.50 USD per kg (derived from other seed/grain prices because there was no local source). For all crops, seed prices were subtracted and the gross margins per crop were summed up to the gross margins per field. When labour was hired, farmers indicated the total costs per activity per field. These costs, together with the costs of biocide, were also subtracted when used.

Gross margin from livestock was based on the information provided about livestock sales in 2017. The amount of money earned by selling livestock is added up for all the sold livestock, and the money spent on buying livestock is subtracted. Feed costs were limited since the main consumption was grass on and around the farm and little feed was purchased, and was therefore not included. The income from milk sale was calculated by averaging the daily production in the wet and dry season and by multiplying it with the price per litre and the 135 days approximation of the season duration.

The gross margin from the farm was considered to be the gross margin from the field and from livestock. For the farm households that also had other sources of income, the percentage of other income indicated by the farmers was added and an estimation of that income was made by comparing it to the gross margin from farming. Produce consumed by the household is not taken into the calculation. No expenditures of the family were considered.

All currencies were converted from Ugandan Shilling (UGX) to US Dollar (USD) with a conversion rate of 3814 UGX per USD, which was the actual conversion rate during the field work.

2.5.6. Statistical analysis

All data was entered in Microsoft Excel, and all calculations and analyses were done in software package R (version 3.5.1). Analyses of variance (ANOVA) and Welch Two Sample t-tests were used to detect statistically significant differences, after checking the validity of the assumptions underlying this test with Shapiro Wilk's test for normality. If the data was not normally distributed, a logarithm transformation was applied. Means were separated using Fisher's least significant difference (LSD) test at 5% probability level for ANOVAs. Table 4 shows what was tested with what method.

Table 4. Subjects statistically tested.

Subject	Test	Data transformation
Farm and household characteristics (Table 5)	ANOVA	-
Soil characteristics per farm type (Table 8)	ANOVA	-
Soil characteristics of fields with soybean and other crops (Table 9)	t-test	-
Yield of bean, groundnut, maize, soybean and sunflower (Figure 11)	ANOVA	Log-transformation
Yield of maize and soybean per farm type (Figure 12)	ANOVA	Log-transformation, only for maize
Yield and variety (Ch. 3.6)	t-test	-
Labour use for soybean and other crops (Figure 8)	t-test	Log-transformation
Labour use for land preparation with and without ox plough (Ch. 3.4.4)	t-test	Log-transformation
%Ndfa in MA-HL and SA-LL farmers (Table 11)	t-test	-
%Ndfa and variety (Figure 9)	t-test	-
Soybean share in household income per farm type (Ch. 3.7)	ANOVA	-
Household income (Ch. 3.7)	ANOVA	Log-transformation
Household income per adult (Ch. 3.7)	ANOVA	Log-transformation
Soybean share in household income and food security (Ch. 3.7)	ANOVA	Log-transformation
Income per adult and food shortage (Ch. 3.7)	ANOVA	Log-transformation

3. Results

3.1. Farm typology

Farmers were categorized based on farm size and TLU. Livestock ownership was ranging from 0 to 7.5 TLU per household. Above 4.6 TLU a farm was classified as 'high livestock', and below 0.6 TLU as 'low livestock'. 'Medium livestock' had a TLU value in between. Farm size was classified as 'large' with an area larger than 4.6 ha. Small size farms had an area below 1.7 ha. Medium size farms were smaller than 2.9 ha, but could also be smaller than 1.7 ha, size was not a distinguishing characteristic for those farms. The majority of the famers were the 'medium area' and 'high livestock' (MA-HL) or 'small area' and 'low livestock' (SA-LL) type, but there are also farmers in the 'large area' and 'medium livestock' (LA-ML) type. One farmer could not be placed in one of the three farm types. The grouping is based on the farm size and TLU is demonstrated in Figure 5. Characteristics of the farm types are given in Table 5.

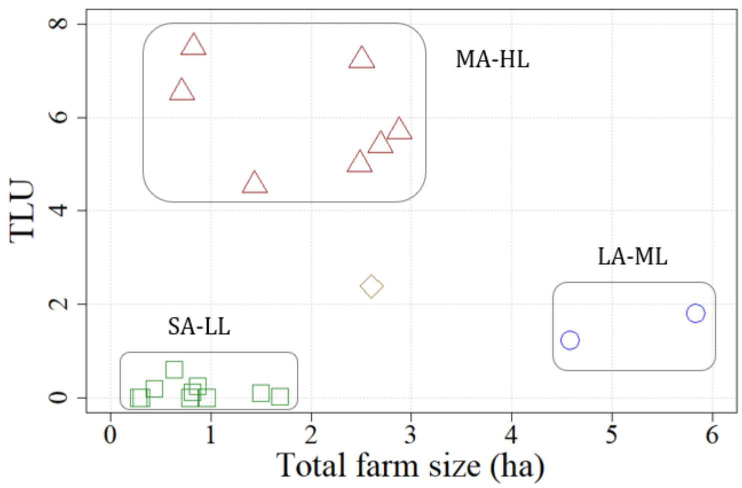

Figure 5. Farm categorization based on Tropical Livestock Unit (TLU) and farm size. Farm types MA-HL (medium area - high livestock), LA-ML (large area - medium livestock) and SA-LL (small area - low livestock) are clustered. One farm could not be included in a farm type.

LA-ML farmers had the largest farms and some livestock, less than MA-HL farmers. Half of their goods was produced for the market, although a large proportion of land was covered with cash crops (Figure 6). LA-ML farmers used most hired labour, and always had access to an ox plough.

MA-HL farmers had a smaller farm than LA-ML farmers and larger than SA-LL farmers. They had most livestock. Their production focus was similar to LA-ML farmers, but more market oriented than SA-LL farmers. Also family size was larger in MA-HL households than in SA-LL households. Like LA-ML farmers, MA-HL farmers also had access to an ox plough. Among MA-HL households, there were no young couples.

SA-LL farmers had the smallest farms. They had little livestock, significantly less than MA-HL farmers and almost significantly less than LA-ML farmers. SA-LL farmers hired less labour than LA-ML farmers. Not all SA-LL farmers could access an ox plough, and used a hand hoe on the field only. The age of the household heads in SA-LL households was most diverse, with young couples (21 years old) and elderly people (up to 70 years old).

Table 5. Characteristics of the farm types (n=20) in 4 sub-counties. With information from the household survey, except the average farm size (which was measured). Characteristics with a "*" were used to construct farm types. For the average farm size, TLU, family size and age of the household head, the range is given between brackets. One of the farm households could not fit in any of the types and is therefore left out. Letters indicate the significance of the difference. Characteristics without letters could not be tested for significance. Distinguishing characteristics significantly vary between farm types.

Characteristic	LA-ML Large area medium livestock	MA-HL Medium area high livestock	SA-LL Small area low livestock
Number of farm households of the type (*n*)	2	7	10
Distinguishing characteristics			
Average farm size (ha)*	5.2[a] (4.6 – 5.8)	1.9[b] (0.7 – 2.9)	0.8[c] (0.3 – 1.7)
Median Tropical Livestock Unit (TLU)*	1.5[b] (1.2 – 1.8)	5.7[a] (4.6 – 7.5)	0.1[b] (0.0 – 0.6)
Production orientation: goods produced for market[1]	50%[ab]	71%[a]	11%[b 6]
Use of hired labour[3]	75%[a]	50%[ab]	25%[b]
Average family size	9[ab]	9.4[a] (7-15)	6.4[b] (3-12)
Describing characteristics			
Access to ox plough	100%	100%	50%
Income from farming	90%	87%	91%
Improved seeds used[2]	88%	68%	48%
Farming knowledge (% trained)	100%	71%	80%
Input use[4]	50%	21%	10%
Education level of household head[5]	1[a]	1.7[a]	1.2[a]
Average age household head	± 40[a]	44[a] (37-52)	37[a] (21 – 70)
Member of a farmer cooperative	50%	57%	60%
Influenced by N_2Africa	50%	29%	33%
Other sources of income	Trade (1/2)	Trade (2/7) Alcohol sale (1/7) Salary (1/7)	Salary (3/10) Alcohol sale (1/10)

[1] Production orientation was scored 0% if production was for home consumption, 50% if production was for market and home consumption, and 100% if the production was for the market only.
[2] Improved seeds use is scored 0% if local seeds are used, 50% if both local and improved seeds are used, 75% if the majority of seeds used is improved, and 100% if improved seeds are used.
[3] Use of hired labour is scored 0% of only family labour is used, 50% if labour is sometimes hired and 100% if labour is always hired.
[4] Use of inputs is scored 0% when inputs are never used and 50% if inputs are sometimes used.
[5] Education level is scored from 0 to 3. 0 is illiterate, 1 is primary education, 2 is secondary education and 3 is higher education.
[6] n = 9, data missing

3.2. Farming system description

3.2.1. Crop production in Oyam

In season 2017B soybean was cultivated by 25% of the farmers, on 10% of the farmland when looking at all farms together (Table 6). In this season, more land was covered with cereal crops and other cash crops than in season 2018A.

In season 2018A, soybean covered 41% of the land of all farms together and was therefore the most cultivated crop (Table 6). This was in line with the findings of the household survey, where 60% of the farmers indicated that soybean was the most important crop for their farm. The only other cash crop grown in season 2018A was sunflower, which covered 20% of the area and was grown by a quarter of the farmers. Cereal crops were found on almost every farm, but only in small quantities. The majority of the farmers (70%) also cultivated other legumes, of which bean was most important.

Table 6. The percentage of farmland allocated to a crop type (or fallow land) and the percentage of farmers allocating land to this crop type in season 2017B and season 2018A.

	2017B		**2018A**	
Crop type	**% of farmland**	**% of farmers**	**% of farmland**	**% of farmers**
Soybean	10	25	41	75
Cereal crops[1]	34	65	5	90
Other cash crops[2]	29	65	20	25
Other legumes[3]	8	50	10	70
Non-legumes[4]	11	75	9	75
Fallow	8	40	15	55

[1] Crops in this category are maize, millet and sorghum.
[2] Crops in this category are cotton and sunflower.
[3] Crops in this category are groundnut, bean and pea.
[4] Crops in this category are sesame, cassava, banana, sweet potato and local vegetables.

The area covered with soybean was more than four times larger in season 2018A than in season 2017B, and 75% of the farmers cultivated soybean in 2018A. The area with cereals was smaller in season 2018A than in season 2017B, although this could largely be explained by the commercial cereal cultivation of one of the LA-ML farmers and one of the MA-HL farmers (Figure 6a). Sunflower covered more than one fifth of the area in 2018A but other cash crops were cultivated by more farmers in 2017B. Other legumes were cultivated by more farmers in 2018A, but the area remained similar. More land was fallow in season 2018A.

Cash and food crops

Information about the sale and consumption of crops was given by the farmers in the household survey. Soybean was mostly sold, but was also kept at home by some farmers in small quantities. Cotton and sunflower were only sold as cash crops. Groundnut and sesame were both used for home consumption and were also sold. Bean, pea and cassava were mostly cultivated for home consumption, but also sold in smaller quantities. Maize was both a cash and a food crop. Sweet potato was always cultivated for home consumption.

Consecutive crops

No insight in the full crop rotations was provided by the farmers, but the main crops grown consecutively in season 2017A, season 2017B and season 2018A were known and listed in Appendix IX. On 12% of the fields, there was a consecutive cultivation of soybean and cereals. Cassava was produced consecutively on 5% of the fields.

3.2.2. Land allocation at farm level

A large variation between individual farms, between farm types and within farm types could be observed in both season 2017B and season 2018A (Figure 6). A large difference between farm types, besides the farm size, was the diversity of crops. LA-ML farmers grew few different crops, where the systems of most MA-HL and SA-LL farmers were more diverse and with smaller areas of one crop. LA-ML and MA-HL farmers grew more cereals in 2017B and reduced this area in 2018A, most SA-LL farmers did not grow much cereals in 2017B nor in 2018A. Other non-legume crops were mostly grown by SA-LL farmers, in both seasons. LA-ML farmers did not have any fallow land. Most farmland was owned by the farm household. LA-ML farmers owned 100% of the farmland, MA-HL farmers owned 89% of the farmland and SA-LL farmers owned 74% of their farmland.

Also farms within a farm type were different. SA-LL farmers grew mostly for home consumption, but some also allocated land to cash crops. In both seasons, some farmers chose to focus more on cash crops, where others had a more diverse system with a mix of cereals, other legume- and non-legume crops. Also MA-HL farmers had different approaches, some grew large areas of a monoculture and others had more diverse farms.

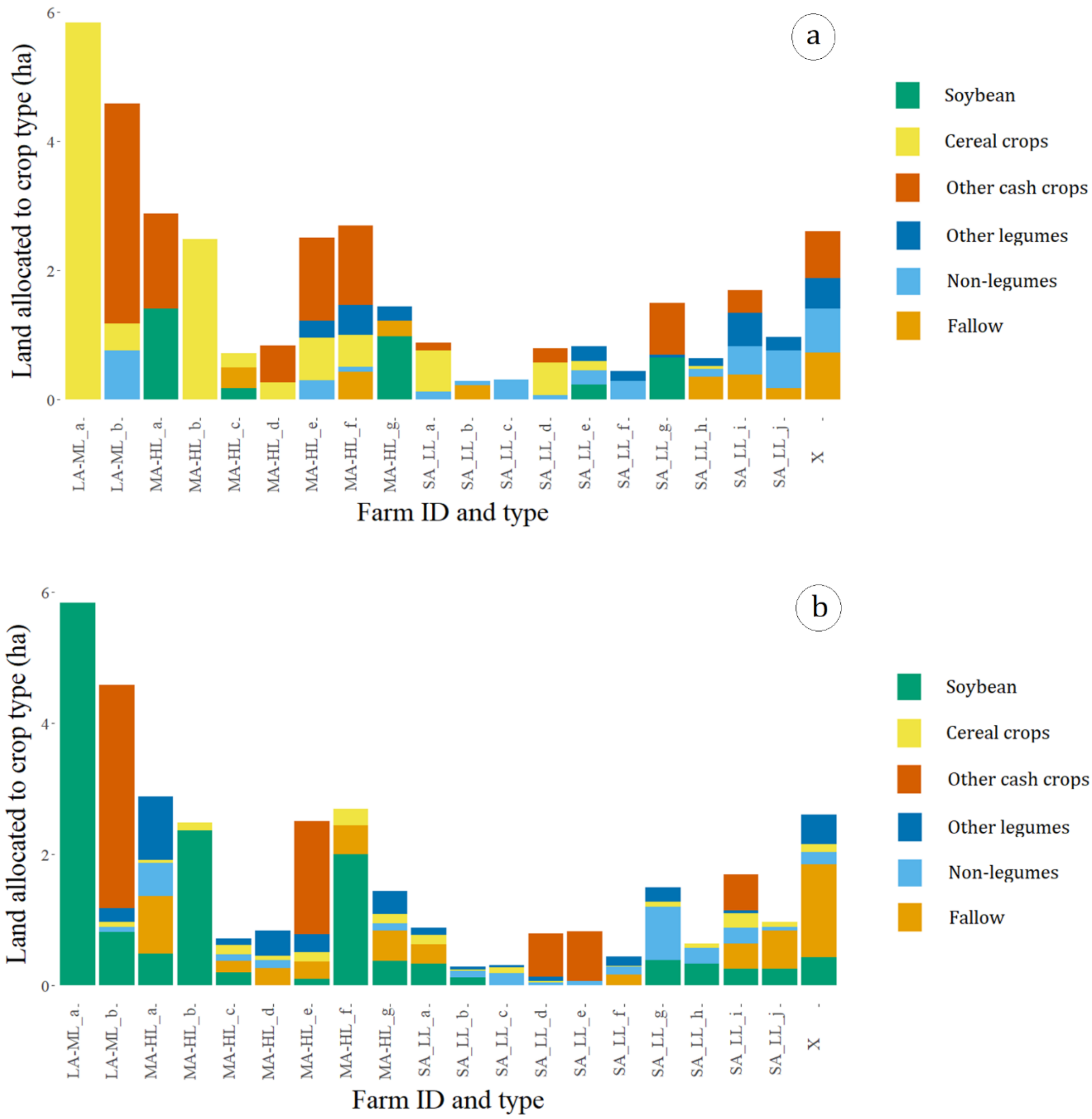

Figure 6. *Land allocation to different crop types on the individual farms in season 2017B (a) and season 2018A (b). LA-ML: large area – medium livestock. MA-HL: medium area – high livestock. SA-LL: small area – low livestock. Cereal crops: maize, millet and sorghum. Other cash crops: cotton and sunflower. Other legumes: groundnut, bean and pea. Non-legumes: sesame, cassava, banana, sweet potato and local vegetables.*

3.2.3. Land allocation to soybean

When looking in more detail into the land allocation to soybean in both season, differences between farm types and seasons could be seen. In 2017B, most land was allocated to soybean by MA-HL farmers. LA-ML farmers did not allocate any land to soybean, and SA-LL also didn't except for two out of ten (Figure 7a). In 2018A, most allocation to soybean was by LA-ML farmers, followed by MA-HL farmers and least land was allocated by SA-LL farmers. However, the differences within types were large and the differences between the types were small. Especially MA-HL farmers varied the allocation from 0% to almost 100%. SA-LL farmers most often allocated around a quarter of their farmland to soybean, and never grew on more than 55% of their farm (Figure 7b).

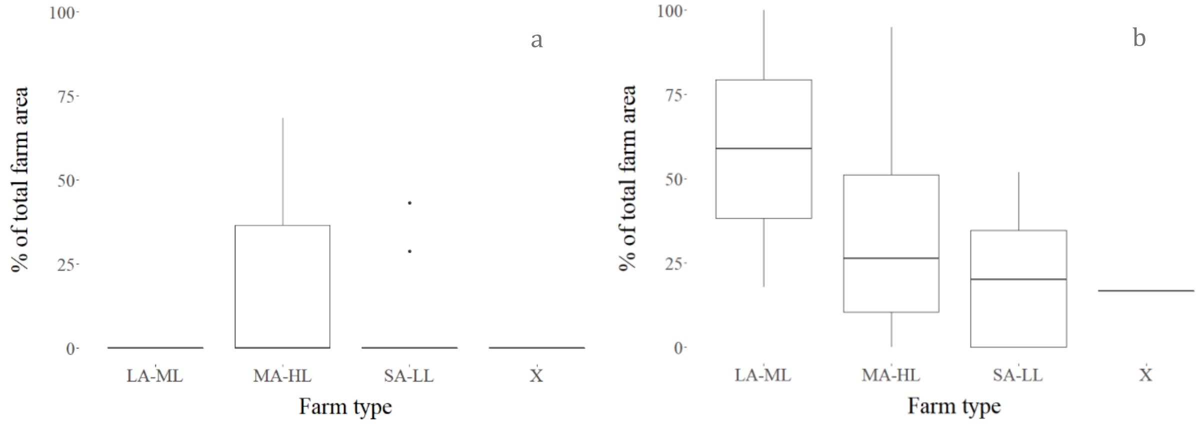

Figure 7. Percentage of land allocated to soybean for the different farm types in season 2017B (a) and 2018A (b). LA-ML: large area – medium livestock. MA-HL: medium area – high livestock. SA-LL: small area – low livestock. X: Type X.

On 62.5% of the fields, soybean was grown in intercropping with other crops (Table 7). Monocropping and intercropping with maize occurred on the same number of fields. Intercropping with cassava was another common practice, done on 12.6% of the fields. On all other fields, soybean was intercropped with a large diversity of other crops. Most monocropping (11 of the 12 fields) was done on fields of LA-ML and MA-HL farmers, only one SA-LL field had soybean as monocrop.

Table 7. Intercropping and monocropping with soybean in season 2018A. n = 33.

Crop system	%
Soybean monocropping	37.5
Soybean – maize intercropping	37.5
Soybean – cassava intercropping[1]	12.6

[1] Some fields were with soybean and cassava only, some also had maize.

3.2.4. The role of livestock

Livestock ownership had several purposes for farmers in Oyam. Oxen were used to work on the field, and some cows provided milk. Other purposes of livestock ownership, mainly cattle and goats, were saving, insurance and dowry. Consumption was often not the main purpose of having animals, but some farmers consumed the meat. Sale of animals was a source of income, but not a main source of income (Ch. 3.7).

3.3. Soil characteristics

During the field survey, farmers were asked to give their view on the soil fertility of a field. Of all fields, 28% was perceived fertile, 42% medium fertile, 30% poor. From the sampled soybean fields, one of the two LA-ML fields was perceived as good, the other as poor. Two of the MA-HL soils were perceived as poor, and one as good. One of the SA-LL fields was perceived as medium fertile, the other three were perceived poor. Soils of SA-LL farmers were richer in organic and in nitrogen than soils of MA-HL farmers (Table 8). Soils of LA-ML farmers were also richer in organic matter (p = 0.086) and nitrogen (p= 0.059) than soils of MA-HL farmers but those differences were not significant. Other characteristic were not significantly different for the farm types. However, generally LA-ML and SA-LL soils were more similar and MA-HL soils were different. What caused this difference was not clear and this could not be tested due to the small sample sizes. Soil texture was not different for the different types and soils had an average sand fraction of 53%, clay fraction of 16% and silt fraction of 31%.

Table 8. Average soil characteristics for fields from farmers from the three different farm types. Letters indicate the significance of the difference between the values per column.

Farm type	***n***	**pH**	**OC** **$g\ kg^{-1}$**	**Total N** **$g\ kg^{-1}$**	**P** **$mg\ kg^{-1}$**
LA-ML	2	6.1 ^{a}	32 ^{ab}	1.36 ^{ab}	7.5 ^{a}
MA-HL	3	6.1 ^{a}	19 ^{a}	0.80 ^{a}	11.3 ^{a}
SA-LL	4	6.1 ^{a}	34 ^{b}	1.46 ^{b}	8.5 ^{a}
Total	9	6.1	28.7	1.22	9.2

Of all fields with soybean as the main crop, 26% was perceived fertile, 45% medium fertile and 29% poor. This was following the trend of all fields, and therefore there seemed to be no specific allocation to soybean to rich or poor fields. There was no significant difference found between soils on which soybean or other non-legume crops were grown (Table 9).

Table 9. Average soil characteristics per crop type allocated to the field in season 2018A.

Main crop	***n***	**pH**	**OC** **$g\ kg^{-1}$**	**Total N** **$g\ kg^{-1}$**	**P** **$mg\ kg^{-1}$**
Soybean	4	6.0	23	1.00	9.3
Non-legumes[1]	4	6.2	36	1.52	8.5

[1] Two fields with cassava and two fields with sunflower as main crop.

3.4. Cultivation techniques and inputs

3.4.1. Soybean variety

On 45% of the fields with soybean as the main crop in season 2018A, soybean varieties used were unknown. Namsoy 2 was used on 32% of those fields, Maksoy 2N, Maksoy 3N and Namsoy 1 were found on 6% of the fields, Namsoy 4 was found on 3%. LA-ML farmers used Namsoy 2 on half and Maksoy 2N on one third of the soybean fields, MA-HL farmers used Namsoy 2 on 47% of the fields, other improved varieties on one third of the fields and the variety was unknown on 20% of the fields. SA-LL farmers were not aware of the variety used on their fields.

3.4.2. Residue use

Most crop residues were left in the field. In season 2017B, 61% of the crop residues was left in the field. On soybean fields, this was also the case on 78% of the fields. The planned residue use for season 2018A was for 65% of the fields also leaving it in the field. For the other 35% of the fields, the planned residue use was either burning it, collecting it for a fence or feeding it to livestock. Cassava was often replanted, and therefore also collected. LA-ML farmers left residue in 88% of the fields in 2017B and on the same number of fields in 2018A. MA-HL farmers left residue in 84% of the fields and planned to leave residue on 89% of the fields in 2018A. SA-LL farmers left residue in 57% of the fields and planned to leave residue on 68% of the fields in 2018A. In the fields with soybean as main crop, residues were planned to be left in the field in 77% of the fields. In season 2018A the planned residue use was leaving it in the field on 83% of the LA-ML fields, 93% of the MA-HL fields and 56% of the SA-LL fields.

3.4.3. Input use

The use of chemical fertilizer, manure, biocides and inoculants was very limited. Actual use in the field is given in Table 10.

Table 10. Number of farmers using inputs on at least one of their fields in growing season 2017B and 2018A.

	Chemical fertilizer		Manure		Inoculants		Biocide	
Farm type	*2017B*	*2018A*	*2017B*	*2018A*	*2017B*	*2018A*	*2017B*	*2018A*
LA-ML	0	0	0	0	0	0	0	1/2
MA-HL	0	0	0	0	0	0	2/7	1/7
SA-LL	0	0	0	0	0	0	2/10	0

No fertilizer was used in season 2017B or season 2018A. Some farmers indicated to use fertilizer only once every few years, but most said it wasn't necessary to use it at all because the fields were already fertile enough or that they could not access or afford fertilizers.

The use of manure was not a common practice in the area. Most of the farmers having cattle didn't collect any manure. Some mentioned they sometimes used some to smear the house. The two farmers that did use it in the field, sometimes applied it locally to weak spots in the field or underneath fruit trees. On none of the fields of the field survey manure was applied.

In season 2017B, biocides were used by 4/20 farmers. Two of the farmers were MA-HL farmers, and two were SA-LL farmers. One of the MA-HL farmers used it on soybean as well, the other three only used it on cotton. In season 2018A, biocides were used by one of the LA-ML farmers on most of the soybean fields. Also, the MA-HL farmer that used biocides in the season 2017B as well used it again on bean, groundnut and soybean. The other farmers did not use biocides in season 2018A. There is no information about the amount of biocide applied, nor the active ingredients.

None of the farmers used inoculants in season 2017B and season 2018A. Reasons why farmers did not use inoculants were lack of access (they did not know where to buy it) or lack of information about its purposes and use. Not everybody was well informed. One farmer mentioned that she received a package with inoculants from N_2Africa, and applied it in a previous season. After that, she never bought it again for the same reasons as mentioned above.

3.4.4. Labour use

Labour use was not specific to a farm type as can be seen in Appendix XI. More labour days were spent on fields with soybean as main crop ($p = 0.039$) (Figure 8). On a few fields, more than 500 labour days were spent. These high numbers were usually caused by large groups hired by a few MA-HL and LA-ML farmers for several days.

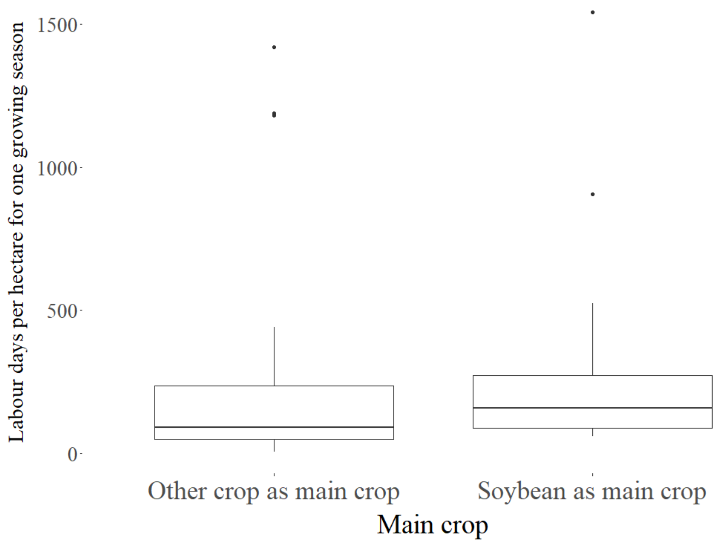

Figure 8*. Labour days per hectare spent in growing season 2018A on fields with soybean as main crop and other crops.*

Around 20% of all labour activities were carried out with an ox plough. 74% of the activities done with an ox plough were land preparation and sowing. Land preparation (ploughing) with an ox plough took less time than with a hand hoe ($p < 0.001$). Labour hiring was done in all farm types. The LA-ML farmer hired labour for all tasks, except for the work done with an ox plough which was done using family labour. SA-LL farmers usually did not hire labour, but 3/10 did for land preparation on one or more of their fields. Labour was hired on most of their fields by 2/7 MA-HL farmers, for preparation and weeding.

3.5. Biological nitrogen fixation

Biological nitrogen fixation was variable, but occurred on all sampled soybean fields (Table 11). The %N derived from N_2-fixation was variable in all farm types, although the highest percentages were found mostly with SA-LL farmers. However, no significant difference was found between MA-HL and SA-LL fields. Too little data was collected to test for LA-ML fields. The amount of nitrogen fixed was smaller for SA-LL farmers than for MA-HL farmers at the end of the season, because they generally had less soybean biomass on the field.

Table 11. Nitrogen derived from the atmosphere by soybean and nitrogen fixed in aboveground parts during the season on soybean fields (moncropping) on all farms.

	$\delta^{15}N$ Weed	**$\delta^{15}N$ Soybean**	**% Ndfa**	**DM Soybean kg ha^{-1}**	**%N Soybean**	**Total N kg ha^{-1}**	**Fixed N kg ha^{-1}**
LA-ML_a	6.12	5.20	11.6	5078	2.5	127	14.5
MA-HL_a	6.24[1]	3.16	38.2	20193	3.0	606	234.3
MA-HL_b	5.39	4.47	12.7	8267	2.5	207	26.0
MA-HL_c	7.57	6.22	14.4	1506	2.3	35	5.1
MA-HL_e	6.24[1]	6.20	0.5	4850	2.7	131	0.7
MA-HL_f	6.40	4.78	19.6	*	1.8	*	*
MA-HL average			*17.1*				*66.5*
SA-LL_a	6.57	5.96	7.3	3908	2.3	90	6.6
SA-LL_b	6.23	3.48	34.1	1602	3.0	48	16.6
SA-LL_g	6.24[1]	5.93	3.9	10106	2.8	283	10.8
SA-LL_h	6.24[1]	2.47	46.7	3840	1.9	73	34.0
SA-LL_i	4.75	1.58	48.2	8022	3.0	241	114.1
SA-LL_j	6.24[1]	4.03	27.4	6033	1.8	109	30.6
SA-LL average			*27.9*				*35.4*
X	6.90	6.60	3.4	3431	3.1	106	3.6
Overall average			***20.6***				***41.4***

[1] An average of the other values, because those weed samples were lost
* Indicates a missing value

The %N derived from N_2-fixation was generally higher in soybean of an unknown variety (Figure 9). Soybean seeds of unknown variety were bought on the regular seed market, and could therefore be both local or improved varieties. Unknown soybean varieties were most diverse and had higher percentages in %N derived from N_2-fixation. This percentage in improved varieties was generally lower and less variable, although there was no significant difference between the means.

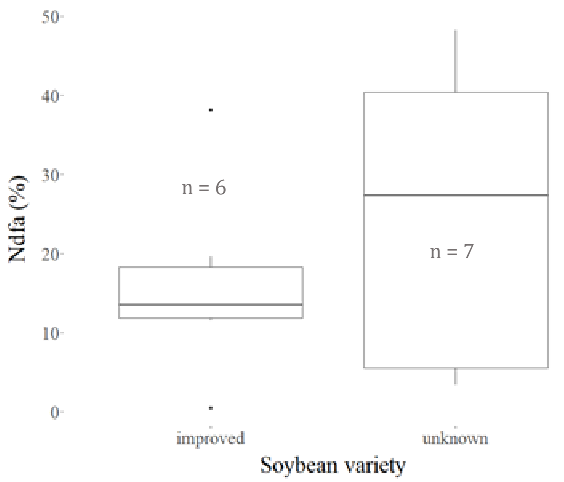

Figure 9. *Percentage of nitrogen derived from atmosphere for improved and unknown soybean varieties. Improved varieties were Maksoy 3N, Namsoy 2 and Namsoy 1.*

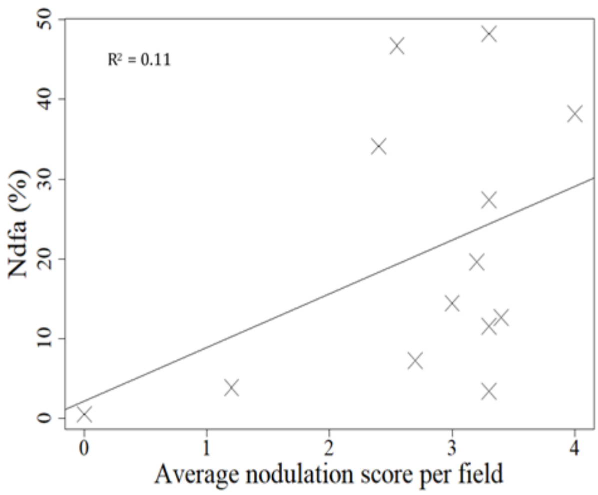

Figure 10. *Nitrogen derived from atmosphere and nodulation score.*

Nodules were found in 12 of the 13 sampled fields. 95% of the tested plants had active nodules, and an average nodulation score of 2.7 on the scale of Bala *et al.* (2010) (Figure 3), which means few to moderate nodulation. Nodulation is crucial for biological nitrogen fixation, as can also be seen in Figure 10. However, moderate nodulation does not guarantee a high biological nitrogen fixation from the atmosphere. Fixation ranged from 3.4% to 48.2%, with similar nodulation (around 3 on the scale of Figure 3).

3.6. Yield

The yield of all crops that were ready for harvesting is given in Figure 11. Cassava and pea needed more time and therefore remained in the field in (part of) the second season. Maize yields were significantly higher. Groundnut, soybean, bean and sunflower yields were not significantly different from each other. Sesame, sorghum and millet were not tested for significance due to their low sample size. The average soybean yield was 1695 kg ha^{-1}.

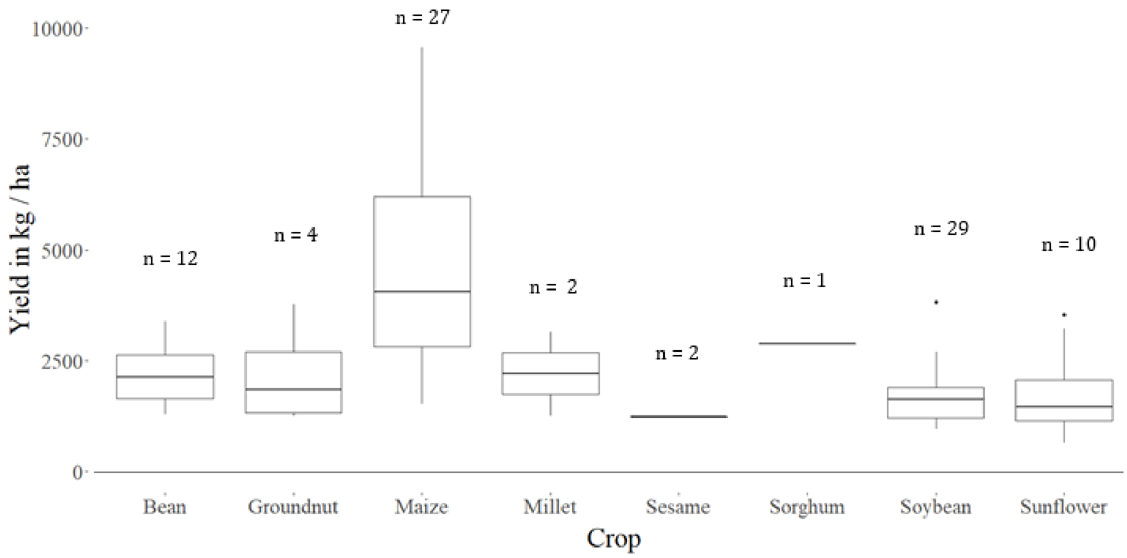

Figure 11. *Grain dry matter yield per hectare of all crops harvested at the end of season 2018A.*

Soybean yields were most variable in fields of SA-LL farmers, and generally also higher (Figure 12a). The outlier in SA-LL, a yield of 3825 kg ha^{-1}, was found on a field that was for 60% covered with other crops and might for this reason have been an overestimation. With this high value, yield was significantly higher for SA-LL farms than on MA-HL farms ($p = 0.026$), but when the value was taken out the difference was not significant ($p = 0.135$). Improved soybean varieties yielded similar to unknown soybean varieties.

Maize yields were more variable than soybean yields (Figure 12b). Although the maize yield was corrected for intercropping fractions, the small intercropping proportions could still have led to wrong interpretations of the yield data. Also, some plants that were not ready for harvesting were left in the field which could have led to an underestimation of yield. If none of this were true, differences in maize yield could also be explained by the diversity of farm systems within a farm type. The difference between MA-HL and SA-LL maize yields was not significant, Type X and LA-ML had too few data points to test.

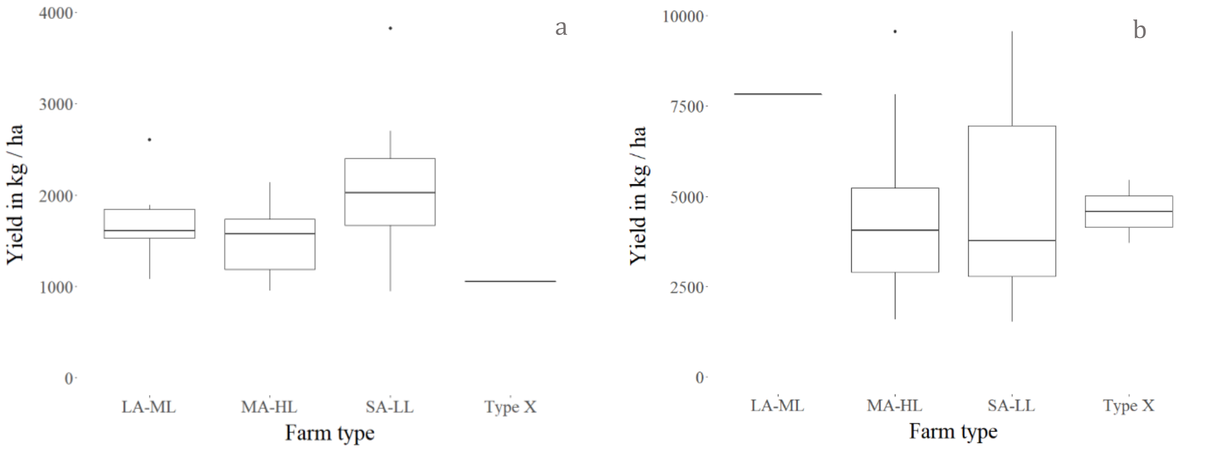

Figure 12. *Dry grain yield of soybean (a) and maize (b) per farm type harvested in the end of season 2018A. n indicates the number of fields on which the yield is measured. LA-ML: large area – medium livestock. MA-HL: medium area – high livestock. SA-LL: small area – low livestock.*

3.7. Income

Soybean was cultivated by farmers of all types and had diverse shares in the total household gross margin (Table 12). However, on average a similar share in gross margin in all types was found. Total household gross margin from SA-LL farm households was lower than from MA-HL households ($p = 0.001$) and lower than LA-ML households ($p < 0.001$). Total household income in LA-ML farmers was higher than in MA-HL households ($p = 0.042$). Household income per adult (person aged above 16) was following this trend. Food shortage occurred in all types, but most often in SA-LL households. There was no relation between the perceived food shortage and the percentage of soybean contributing to the total household income, and neither between perceived food shortage and household income per adult. A full overview of the income from the fields is given in Appendix XII.

Table 12. Gross margin of the season 2018A from crop production and livestock, and the share of soybean cultivation in this. Gross margin from farming and other sources of income added up to the total household income. Whenever there was labour on an intercropped soybean field, the percentage was taken of the total gross margin of the fields together (*). When this was not the case, the percentage is taken of the total gross margin from farming.

Farm type	Gross margin from crops in season 2018A (USD)	% from soybean	Estimated gross margin from livestock (USD)	Total gross margin from farming (USD)	Income from other sources (%)	Total household income (USD)	Household income per adult (USD)	% Soybean in total income	Food shortage perception
LA-ML	3193	100	46	3239	0	3239	540	98.6	Sometimes
	2253	17	85	2339	20	2923	731	13.1	Never
Average	*2723*	*59*	*66*	*2789*	*10*	*3081*	*635*	*56*	
MA-HL	1958	0[2]	229	2187	20	2734	683	0	Never
	1240	93	-3	1238	20	1547	387	74.6	Never
	356	33	211[1]	567	0	567	142	20.7	Sometimes
	228	0	329	557	50	1115	279	0	Never
	1083	4	203	1286	0	1286	161	3.4	Never
	1144	79*	39	1183	0	1183	237	76.4	Never
	524	20	18	541	0	541	108	19.3	Sometimes
Average	*933*	*33*	*147*	*1057*	*13*	*1259*	*280*	*29*	
SA-LL	322	56*	0	322	20	402	201	44.8	Sometimes
	221	40	0	221	0	221	74	40.0	Unknown
	220	0	0	220	0	220	110	0.0	Yes
	419	0	0	419	0	419	140	0.0	Yes
	152[3]	0	0	152	10	169	85	0.0	Never
	348	0	-7	341	0	341	171	0.0	Sometimes
	930	12	18	948	0	948	135	11.8	Never
	360[3]	46	93	453	30	647	108	25.6	Yes
	883	22	0	883	0	883	294	22.0	Sometimes
	165	79	0	165	30	236	118	55.3	Never
Average	*402*	*26*	*10*	*412*	*9*	*449*	*144*	*20*	
X	625	22	28	653	0	653	163	21.1	Yes

[1] 159 USD of this gross margin was from milk sale
[2] This was actually a negative number, since labour expenses rose over the calculated profit. Since it was unlikely that farmers cultivated to lose money, a value of 0 was used.
[3] Banana and local vegetable were ignored on these farms, so income could be higher in reality.

The average yield of maize was higher than of bean, groundnut and sunflower, but the maize grain prices were lower and therefore the crop was not very different in profitability. Soybean prices at the moment of sale were generally good in 2017 compared to other years, but were sometimes low. This was seen as a risk of soybean cultivation. Prices were, according to the farmers, largely influenced by the production in the area and the demand of the buyer and not stable. Other crops, such as maize and bean, would then be a safer choice since they were popular food crops and could always be sold and therefore guaranteed income or food. On the other side, soybean had more income potential on a large scale because there was a larger market available and it could be exported outside of the district like other oilseed crops and cotton. Grains and seeds were usually seen as the same product, but prices were not the same. This was caused by temporal effects: in the sowing period, grains/seeds were more scarce and therefore more expensive. Generally, better-off farmers purchased new (improved) seeds for every growing season, other farmers stored grains at home for usage in the next season, and the poorest farmers needed the seeds for food before the sowing period and therefore had to buy new seeds at the high seasonal price, a vicious circle of poverty.

More than half of the farmers sold their soybean via the cooperative. The grains were bulked there and marketed collectively to a processing company. Some farmers also sold to local stores in their sub-county, and sometimes middle men from the larger companies Mukwano and Maltmero in Lira or (unknown) companies in Gulu (the commercial and administrative capitals of neighbouring districts Lira and Gulu) bought the grains and arranged the transport. The two farmers in Otwal also sold their products directly to those companies. Sunflower was sold via collective marketing in a similar manner, and sometimes also maize. Among the larger companies buying from the cooperatives was Mukwano in Lira, which is an oil seed mill from a larger conglomerate in East Africa, but also other dealers in Lira and Gulu were mentioned. Most other products went to local markets and trading posts in Loro or Minakulu. LA-ML farmers sold more often directly to the companies in Lira than the other farmers.

3.8. Farmers' opinion about soybean

To find out more about the use of soybean in the farm households, an informal conversation was held and some questions were asked. Below an overview is given of the insights acquired during these conversations.

Why did you start cultivating soybean?

7/20 farmers started cultivating soybean after the start of the N_2Africa project, the others already did for a short or longer (one already since 1993) time. One explicitly mentioned N_2Africa as the reason for starting cultivating. 14/20 farmers indicated that they started cultivating for cash as the main reason, because the crop has a good income potential. All others also agreed on this point. The farmers that started 'later' with soybean gave as a reason that they either started farming at that moment, or that they could not afford soybean seeds earlier. Some mentioned that they cultivated it because it was a regular thing to do, and some also mentioned the nutritious value of soybean.

Are you keeping it or selling it?

All 20 of the farmers sold their soybean. For 4/20 farmers this was the only thing to do, but 15/20 also kept small amounts of the harvest at home. A few (3/20) farmers indicated to save seeds for the next season. When consumed, the soybeans were usually roasted, pounded, used for pasting and porridge or as flour. Three farmers said that they were processing soybean into milk, but used this only at home and did not sell those products. 15/20 farmers indicated that the market is reliable, so that there is always a good option to sell. They thought that even when prices are low, soybean still gives an acceptable income. 2/20 farmers disagreed and found the market not very reliable. 7/20 farmers indicated that the prices are dependent on the demand of the buyers. 6/20 farmers thought that the prices were dependent on the amount of soybean produced, becoming lower when there was more production.

What are the advantages of cultivating soybean?

The majority (11/12) farmers that commented on the advantages of soybean underlined the high income potential. One highlighted that the crop is multifunctional because it can be sold or consumed at home. In addition, one farmer added that the crop is nice to cultivate together with other crops. Many farmers mentioned their successes and investments done after good soybean harvest.

What are the disadvantages of cultivating soybean?

Around half (9/20) of the farmers pointed out disadvantages of soybean cultivation. Three of those nine saw the risk of getting low prices as a disadvantage. The year 2016 was mentioned, in which prices were too low to make the cultivation profitable. Two farmers pointed out the high production efforts as a disadvantage. Besides the cultivation, processing also takes a lot of time, one farmer said. Other disadvantages mentioned were the difficulty to combine soybean with other crops (contradicting opinion of another farmer), the weed and pest problem, high costs of production, and the vulnerability of the crop for changes in the weather. In the field survey, farmers were asked what typical problems were on their field. Of all the fields with soybean as main crop, webworm was the main problem in 52% of the fields, pests in 19%, birds in 3% and on 26% of the fields there was no problem.

4. Discussion

4.1. Farm characteristics and typology

The farm selection procedure was not optimal. Most farms could not be categorized according to the typology made after the FDGs (Table 1). In the first place, because farmers never matched all characteristics of a single type and in the second place because the majority of the information on the lists provided by the village heads was inaccurate. This was discovered after acquiring information in the household survey, and there was not enough time to reselect households. Also, the commercial farmers were not represented in the focus area of N_2Africa, so we actively searched for them outside the focus area. This increased the diversity of the sample of farmers in the research, but decreased the suitability of the sample to research the role of N_2Africa. The development of a new typology was required to capture the diversity in the selected households and to cope with the inconsistencies of the initial typology. The uneven distribution of the number of households of a type and the exclusion of the unfitting Type X could have been avoided by using a better selection procedure. The small size of the LA-ML sample was limiting the power of the results regarding farm type.

Livestock ownership was considered an important characteristic of a farm system. It was an indicator of wealth, but also as a means to improve soil fertility by the application of manure. In a study in Kenya, Tittonell *et al*. (2005) observed that organic fertilizers were more frequently used in areas where cattle populations were larger. However, the use of manure on the fields was nihil, also on fields of MA-HL farmers. Tittonell *et al*. (2005) also noted that an inefficient collection, due to for example free grazing which was common in Oyam, was an important reason for the reduction in the use of manure. The livestock management was not focused on the use of manure or residue recycling through livestock, and therefore the MA-HL farm system, apart from the financial and labour-saving benefits, was not functioning essentially different from the others. Nevertheless, the typology did capture differences in farming strategy. SA-LL farmers were cultivating on a smaller area, produced less for the market and had a lower family income than the LA-ML and MA-HL farmers and this was influencing their decision making regarding soybean cultivation.

4.2. Soybean in the farming system

4.2.1. Land allocation

Farmers grew a lot of soybean in season 2018A, 41% of the cultivated area was covered with it. Since the amount of farmers cultivating soybean in the region increased from 35% (Stadler *et al*., 2016) to 75%, it is likely that the cultivated area also increased but there is no information available for the region. Land allocation to soybean was variable in all farms, but the variation was largest for MA-HL farmers that allocated either very little or almost all their land to soybean cultivation. SA-LL farmers also allocated land to soybean, though never on more than half of their farm. Soybean was therefore cultivated by all types of farmers, but the more market-oriented farmers more often cultivated on larger scale. This was in line with the expectations, because it was understandable that more market-oriented farmers could allocate more land to cash crops like soybean than more subsistence-oriented farmers. Land allocation fractions in fields with intercropping were estimated by eye, and considering the low accuracy of this method crop areas could be under- or overestimated.

4.2.2. Soils

In Table 13, average soil characteristics found in Oyam are compared to critical soil values from Fairhurst (2012). Sand fractions in the soils were relatively high. Drainage was therefore likely to be good, but leaching losses could be large. The clay fractions were low, which could have resulted in poor nutrient content and difficulty to increase soil organic matter (Fairhurst, 2012). Phosphorus and nitrogen were often below the critical value and therefore likely to limit crop production.

Table 13. Critical soil values for crop production.

Soil characteristic	Unit	Average Oyam	Critical value (source: Fairhurst, 2012)
pH		6.1	>4.5
OC	g kg^{-1}	29	>15
Total N	g kg^{-1}	1.22	<1.5 Poor N supply.
P	mg kg^{-1}	9.2	< 15 (Bray II) P deficiency likely.
K	mmol kg^{-1}	7.4	>2
Mg	mmol kg^{-1}	9.6	>2
Ca	mmol kg^{-1}	40	>5
Sand fraction	%	53	>50 Leaching losses are likely to be large.
Clay fraction	%	16	<30 Poor nutrient content, poor soil moisture retention.

Organic carbon in the soil was higher in SA-LL fields than in MA-HL fields, but still higher than the critical value of 15 g kg^{-1}. Total nitrogen in the soil was also higher in SA-LL fields than in MA-HL fields, but was low in all fields. The other elements were within the critical values. MA-HL soils were generally the poorest, and had the smallest organic carbon and N content. It was unclear what caused this difference, since none of the farmers applied fertilizers and residue was left in the field less often by SA-LL farmers.

This study would have been better if there was more soil information available. Only one soil sample per farm was analysed, whilst Tittonell *et al.* (2005) described the importance of recognizing the within-farm spatial soil variability which also influences the decision making at farm scale. In addition, the soil data was too limited to look into the relation between soil and biological nitrogen fixation.

4.2.3. Input use

The use of inputs (chemical and organic fertilizers, inoculants, biocides) was low among all farmers. The more market oriented (LA-ML and MA-HL) farmers with more financial means were expected to use more inputs, but they did not except for a few farmers using biocide. The only technology disseminated by N_2Africa that was more widely used, was the use of improved varieties. Farmers were well-informed about the potential benefits of improved varieties. Also, there were enough seeds available and therefore the technology was well-adopted. However, in this study improved varieties did not perform better in both production and fixating nitrogen from the atmosphere but the comparison was not fully valid since the non-improved variety sample consisted of unknown seeds which could still be of an improved variety and was not necessarily of inferior quality. Application of P-fertilizer has shown a high potential in enhancing the soybean yield (Kaizzi *et al.*, 2012a, Ronner *et al.*, 2016, Rurangwa *et al.*, 2018), also in combination with inoculants (Ronner *et al.*, 2016, Rurangwa *et al.*, 2018), but none was used. Also no manure was applied, even though there were farmers with livestock that could collect and apply manure. Starting to do this could be a good practice for improving the soil fertility with available products, although it should be noted that organic inputs cannot substitute mineral fertilizers as both fulfil different functions: while the main role of mineral inputs is to supply nutrients or correct unfavourable soil pH conditions, organic resources replenishes the soil organic matter pool (Vanlauwe and Giller, 2006).

The use of labour was higher in fields with soybean as main crop than in the other fields. The labour availability of an adult was considered the full growing season of around 135 days (given that generally land preparation starts in the beginning of March and harvest takes place halfway July). With an average of 0.43 hectare of land per adult family member, the median labour use with soybean as main crop (159 man-days ha^{-1}) was attainable. This workload was lower compared to the study of Vandeplas *et al.* (2010), who reported labour requirements of soybean cultivation of 178 man-days ha^{-1} when weeding once and 227 man-days ha^{-1} when weeding twice. The median labour use on fields with other crops as main crop of 90 man-days ha^{-1} was very low compared to this. Vandeplas *et al*. (2010) tested several soybean planting methods and input uses (point-placing soybean seeds, applying di-ammonium phosphate and weeding twice), but found that many were unfavourable for resource-poor farmers because the high labour inputs and costs involved did not pay off. They instead proposed using the time instead for collecting locally available inputs such as cooking ashes and farmyard manure to improve the productivity.

A problem that occurred when comparing labour use on fields with soybean as a main crop with labour use of fields with another crop as main crop was that there were also fields with some soybean in the fields with another crop as main crop. Also the labour saved by using an ox plough was not taken into account in this calculation, which was distorting the results since there was a large difference in time required to plough a field with an ox instead of a hand hoe. Harvest and post-harvest processing activities were not considered. To have more certainty whether soybean cultivation requires more labour, labour requirements should have been questioned per crop instead of per field. In addition, no distinction was made between skilled and casual labour. Only casual labour was accounted for, management and off-field activities were not considered.

4.2.4. Biological nitrogen fixation

With an exception of one field, nodules were found in all soybean fields. It was unclear why nodules were not formed on this field, it was a normal field and of moderate fertility according to the farmer. The history of legume cultivation on the field was unknown, leaving the option that the underlying cause was under-infection of the soil with rhizobium. Another possibility is that there were nodules present in lower soil layers and left unnoticed because the sampling for this research was done up to a limited depth. Nitrogen was fixed from the atmosphere in all fields with nodules. The average %Ndfa was 20.6. Compared to the findings of the literature study of Peoples *et al*. (2009) (65-89 %Ndfa) this was low, but it fell in the range of the findings (5-74 %Ndfa) from the literature study by Ronner & Franke (2012). Both environmental (physical and chemical) and management factors can be influencing fixation (Giller, 2001). Environmental factors can be temperature, moisture, toxic effects and nutrient deficiencies. It is unlikely that weather played a large role since it was similar on all fields and the water holding capacity of the fields was comparable. The soil characteristics of the fields in which the BNF samples were taken were unknown, but the other soil data have shown that generally N and P availability in the soil was low which could have limited the N_2-fixation. Management factors that are potentially influencing %N from N-fixation are inoculation, choice of variety, P-fertilization, cropping system (mono- or intercropping) and plant density. An important management factor that could potentially have increased the fixation was inoculation, increases were found ranging from 0 to 55% more fixation in soybean in several studies (Ronner and Franke, 2012). In several studies, potential increases from improved varieties were found, ranging from 1 to 55% (Ronner and Franke, 2012). However, in this study improved varieties fixed less nitrogen than other (unknown) varieties. As mentioned earlier P-fertilizer can improve soybean yield, but the effects of P-fertilizer on nitrogen fixation were not always clear: Ronner and Franke (2012) found percentages of N from N_2-fixation ranging from -3 to -4 in their literature study and also Rurangwa *et al*. (2018) observed no obvious or consistent effect of P-fertilizer or manure use on %Ndfa. In addition, Ojiem *et al*. (2007) observed no increase in %Ndfa in soybean grown with P-fertilizer. Unfortunately this study did not allow observations on fields with P-fertilizer, manure or inoculants. Also the planting density and cropping system could have influenced the %N from N_2-fixation, but the sample size was too small to evaluate this.

With an average of 41.4 kg N ha^{-1}, N_2-fixation was low compared to an average fixation of 193 kg N ha^{-1} for soybean in Africa (Peoples *et al*., 2009). With 50 kg N per ton harvested grain (Fairhurst, 2012), soybean grains export relatively large quantities of N from the field at harvest. With a median yield of 1620 kg ha^{-1}

this would result in an export of around 80 kg ha^{-1} which is exceeding the total fixation on the average field, but in some fields the N_2-fixation could have been contributing N to the soil. In a study of Oijem *et al*. (2007) in western Kenya, up to 74% N from N_2-fixation was found in soybean shoots without the use of inoculants. This was resulting in N_2-fixation of up to 74 kg N ha^{-1}. With an export of N from the field through grain harvest of 53 kg N ha^{-1}, this led to a net input of 21 kg N ha^{-1} into the field. Also in Kenya, higher N_2-fixation was observed when P-fertilizer was applied, but given that there was no increase in %Ndfa with P-fertilizer this must have been caused by the increased biomass. On some soybean fields also negative net contributions of N to the soil were observed. In Kenya, fixation was dependent on the fertility of a field (less fertile fields were very low in P) and closely related to biomass development: a likely cause for the variation in fixation in this research as well. Fixation per hectare is largely defined by the amount of biomass on the field, which was low on many of the fields. Since the biomass of a hectare is calculated based on a plot of 2 m^2, there is a chance that mistakes were made because the plot was not fully representative for the field. Since on most of the fields soybean was intercropped with other crops, actual fixation was lower per hectare.

4.2.5. Yields

The average soybean grain yield was 1695 kg ha^{-1}, which was high compared to an average grain yield of 750 kg ha^{-1} without the use of fertilizer found in a study done by Kaizzi *et al*. (2012a) in Ngetta, a region close to Oyam in a similar climate zone according to Wortmann and Eledu (1999). Soil organic carbon was similar in Ngetta, but the P content of the soil was lower. In Oyam, variability between the yields of a single crop was high, but it was not clear whether this was due to measuring mistakes or due to variations in growing conditions. The soil data was too limited to research the relation between soil characteristics and yield, but variation and soil properties including soil organic carbon does not always account for variation in grain yield (Kaizzi *et al*., 2012a).

The reliability of the yield data was low because of the low intercropping fractions that were estimated by eyesight and could therefore deviate. In addition, the harvested plots were 100 m^2 and if its representativeness was wrongly estimated, this could have large effects on the harvest per hectare. The fact that SA-LL farmers had the highest soybean yields could have been related to this, or it could be to a better and more focused management due to their small-scale cultivation. Not all maize was harvested, and the indication of what proportion of maize was left in the field was lost. Actual maize yields could therefore have been higher, and the reliability of the data is low. The average yield in Oyam, 4681 kg ha^{-1}, is very high compared to the study of Kaizzi *et al*. (2012b) in which an average maize yield of 1790 kg ha^{-1} was found on several study sites in Uganda.

4.2.6. Income

There was no relation between the share of soybean in the total household income and the problem of food shortage. Food shortage is a slightly vague concept, and too little specification was asked in this research to fully understand the problem of food shortage in Oyam. Besides farming, no household expenses such as school fees and leisure were taken into account. Also, the household's food consumption was not considered for the calculation of household income. The purchasing power was therefore not equal to the household income, which could get very marginal with the consumption requirements in mind. Soybean consumption was very limited in the area, the majority was sold. The high protein content of soybean was therefore not fully enjoyed though the increased cash income also brought options to buy food. Food supply and income from banana trees, mango trees and vegetable gardens were not included in this research, but were important food sources for the farmers.

4.3. Reflecting on role of N_2Africa

4.3.1. Developments since the start of the project

In the baseline survey from 2014 from Stadler *et al*. (2016), soybean was cultivated by around 35% of the households in the northern region (Oyam and Kole). In this research 75% of the farmers cultivated soybean in season 2018A. Although the sample size was small, this could be an indication that more farmers cultivated soybean. Another finding of the baseline survey was that only 3% of the farmers in Uganda were involved in collective marketing. In this research more than half of the farmers sold their products collectively via the cooperative, bearing in mind that the research locations were located close to N_2Africa targeted cooperatives. Another development was found in the residue management. In 2014, 60% of the crop residue was burned and 30% was left in the field and mulched in the northern region. In season 2017B and 2018A, more than 60% of the crop residues were left in the field for mulching. A considerable amount of farmers (7/20) started cultivating soybean because of the N_2Africa project. The marketing potential and acceptable yields made it a popular crop. Awareness about soybean and nitrogen fixation was widely noticeable in conversations with farmers, the cooperatives were an important stakeholder for storage and sale of soybean and the LSB farmers did manage to supply soybean seeds to a considerable amount of farmers.

4.3.3. Side notes on the project

Although the project influence was widely noticeable, a difference in technology use was found between the farm types: SA-LL farmers mostly didn't use improved soybean varieties, which could be seen as a reason to question the equality of the distribution of project benefits. LSB farmers were influential people in the community and personally involved in the management of the farmer cooperatives. Although there was extra labour involved, the sale of seeds provided more income than the sale of grains (not taken up in the economic analysis). LSB farmers were generally more wealthy and in a favourable position, which could enlarge the difference in wealth classes among the farmers. With the cooperatives as epicentres of the N_2Africa influential sphere, not all corners of the district were reached. No direct influence of the project was noticed by the farmers in Otwal, and it is likely that also other sub-counties at further distance were not influenced evenly.

4.4. Soybean cultivation in the future

Soybean cultivation has brought benefits to Oyam for a long time, and the N_2Africa project seemed to have increased these benefits. The crop is well integrated in the farming systems of small and large scale farmers, and contributes in several ways to the household welfare. However, also problems were encountered that reduced the beneficial effects and the technologies disseminated by N_2Africa were not fully put into use. Increasing the area for soybean production could in the future potentially be beneficial for the farmers, provided the associated problems are taken into account. It should be considered that some farmers, especially the SA-LL farmers, are largely subsistence farmers and their vulnerability should be taken into account if their farmland is used for other purposes than consumable products. The imminent problem of nutrient depletion is not likely to be solved with the currently used soybean cultivation methods, but there is plenty of space left for improvements in the future.

Some things to consider:

- Soils were not in an optimal condition, low supplies of N and P were possibly limiting crop production and nitrogen fixation, catching farmers in the loop of low soil fertility. Applying (P) fertilizer could improve the soybean yields and therefore also increase the biological nitrogen fixation.
- More time could be investment in improving soil fertility with locally available products (such as manure) since external inputs were difficult to purchase and labour was not a limiting factor.
- The use of inoculants and P-fertilizer was minimal, and also after the project efforts not easily accessible. To maximize the benefits of soybean cultivation the purchasing of those inputs should be facilitated and stimulated.
- Pests (mainly webworm) and diseases were still a problem in soybean cultivation, for which solutions should be found, especially if the production area increases.
- The value chains of the soybean sale and trade as well as the connections with the oil mills were not fully clarified in this research. These stakes could be of importance to stabilize the soybean prices and thus reduce risks for farmers, and to improve the negotiation position of farmers.

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Appendix I – Typology used for household selection

The farm characterization based on the FGDs and stakeholder verification. Table I gives the description based on the main criteria, and below a description of the types is given.

Table I. Initial description of the farm types based on the main criteria considered for their categorization as constructed after the FGDs and stakeholder verification.

Farmer type	Production orientation	Land size	Tool use	Seed use	Farming knowledge	Labour	Input use[2]
1	Market	>10 acres	Tractor or ox plough	Improved seeds	Trained	Always hiring labour	Yes
2	Market > consumption	5-10 acres	Sometimes access to ox plough	Improved seeds > home seeds	Trained	Sometimes hiring labour	Sometimes
3	Consumption > market	2-5 acres	Sometimes access to ox plough	Home seeds[1] > improved seeds	Sometimes trained	Not hiring labour	Sometimes
4	Subsistence	<2 acres	Hand hoe (never ox plough)	Home seeds	Not trained	Not hiring labour	None

[1] This can also be improved seeds that are used for too many seasons
[2] Inputs such as inoculants, fertilizer and pesticides

Farmer type 1: Commercial farmers

Commercial farmers have large land holdings and a high production. The farming activities are all done for income, and the focus is on the market. They are generally wealthy, and have capital available to improve their farms. They are able to spend money on inputs such as pesticides, fertilizer and inoculants for the leguminous crops, on quality seeds and on labour (hiring). Commercial farmers are generally better educated, use a tractor or an ox-plough to work the land and are in the possession of more and larger (cattle instead of goats) livestock. The lands of a commercial farmer are scattered around the area, and not located around the homestead.

Farmer type 2: Modern farmers

Modern farmers are farmers that produce for both home consumption and for the market. They have less land than commercial farmers, but can still use a large amount of their land for producing cash crops. Most farmers in this category have access to an ox plough and use improved cultivation methods. Some of them can afford inputs such as fertilizer, pesticides and inoculants, others can't or don't use it for other reasons. They generally use improved seeds, and can buy this every season. They are well-trained and organized. They sometimes hire labour, but also use family labour to work the fields.

Farmer type 3: Traditional farmers

Traditional farmers are farmers that do not own a lot of land, and have to work hard to achieve yields that are high enough to feed the family. When they have good yields, they also bring their surpluses to the market. Some also grow cash crops. They generally do not use quality seeds, and save seeds at home for the next season. Some of them have access to improved seeds via for example a farmer cooperative, but then they use them for many seasons which leads to a reduction in seed quality. They do not use improved agricultural methods such as organized sowing. They work the lands with a hand hoe, and in some exceptions with an ox plough. Sometimes they unite to work together on each other's fields. Normally family labour is used.

Farmer type 4: Subsistence farmers

Subsistence farmers are farmers that are very poor, and dependent on their yields to sustain themselves. They own very small pieces of land, on which they work with the family. They can't afford more land, quality seeds, inputs, and have no access to capital or loans. They use an hand hoe to work the land. Some of them are trained, but can't apply their improved methods due to other constraints such as land ownership and gender issues (for example men that don't allow their wives to apply improved methods). Subsistence farmers are known for their poor financial management.

Appendix II – The household selection criteria compared to the findings of the detailed farm characterization

Table II. The characteristics used for selecting the farm households for the detailed farm characterization, with the results of the detailed farm characterization.

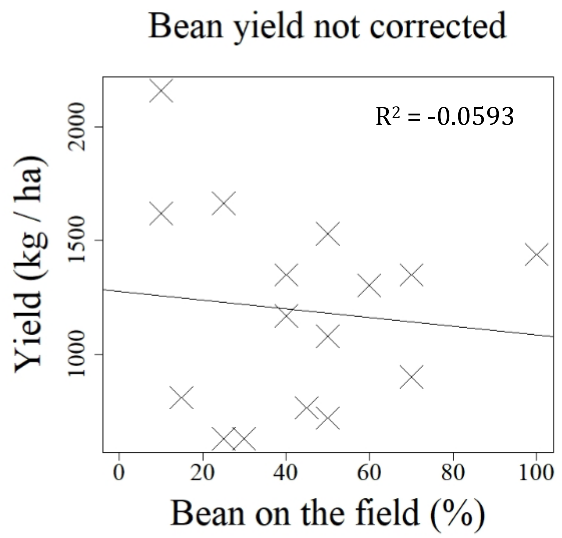
Farm ID	Initially selected as farm type	Production orientation	Farm size (acres)	Access to ox plough	Seed use	Farming knowledge	Labour	Input use
LA-ML_a	1	Market > consumption	14.41	yes	Improved > Local	Trained	Sometimes hiring labour	Sometimes
LA-ML_b	1	Consumption > market	11.33	yes	Improved = Local	Trained	Hiring labour	Sometimes
MA-HL_a	1	Market > consumption	6.46	yes	Improved	Trained	Sometimes hiring labour	Sometimes
MA-HL_b	1	Market > consumption	6.14	yes	Improved > Local	Trained	Hiring labour	Sometimes
MA-HL_f	1	Market > consumption	6.65	yes	Improved > Local	Trained	Sometimes hiring labour	Sometimes
MA-HL_e	2	Consumption > market	6.19	yes	Improved = Local	Trained	Sometimes hiring labour	Never
MA-HL_g	2	Market = consumption	3.55	yes	Local	Not trained	Not hiring labour	Never
MA-HL_c	2	Market = consumption	1.76	yes	Improved > Local	Trained	Sometimes hiring labour	Never
SA-LL_g	2	Market > consumption	3.70	no	Improved > Local	Trained	Not hiring labour	Never
SA-LL_i	2	Consumption > market	4.17	yes	Improved > Local	Trained	Sometimes hiring labour	Never
X	3	Consumption > market	6.43	yes	Improved > Local	Trained	Sometimes hiring labour	Never
MA-HL_d	3	Market > consumption	2.05	yes	Improved > Local	Not trained	Sometimes hiring labour	Never
SA-LL_j	3	*	2.39	yes	Improved > Local	Trained	Sometimes hiring labour	Sometimes
SA-LL_h	3	Consumption > market	1.57	no	Local	Trained	Sometimes hiring labour	Never
SA-LL_e	3	Market > consumption	2.02	yes	Improved > Local	Trained	Sometimes hiring labour	Never
SA-LL_a	4	Consumption > market	2.16	yes	Local	Trained	Not hiring labour	Never
SA-LL_f	4	Consumption > market	1.09	no	Improved = Local	Not trained	Not hiring labour	Never
SA-LL_c	4	Consumption > market	0.76	no	Improved > Local	Trained	Sometimes hiring labour	Sometimes
SA-LL_d	4	Consumption > market	1.95	yes	Improved = Local	Trained	Not hiring labour	Never
SA-LL_b	4	Consumption > market	0.69	no	Local	Not trained	Not hiring labour	Never

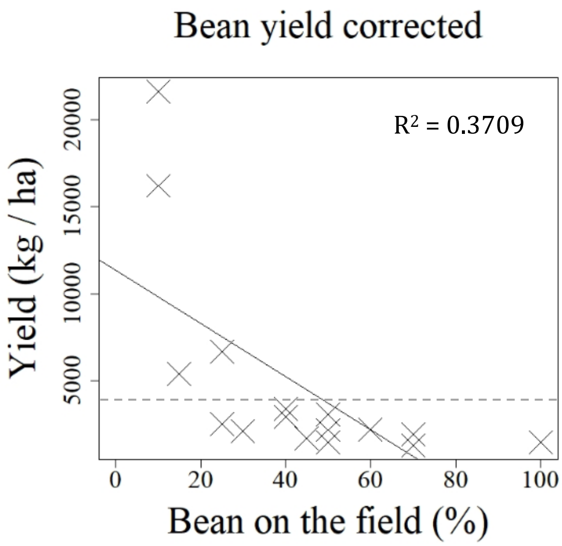
Appendix III – Relative weights for calculating TLU

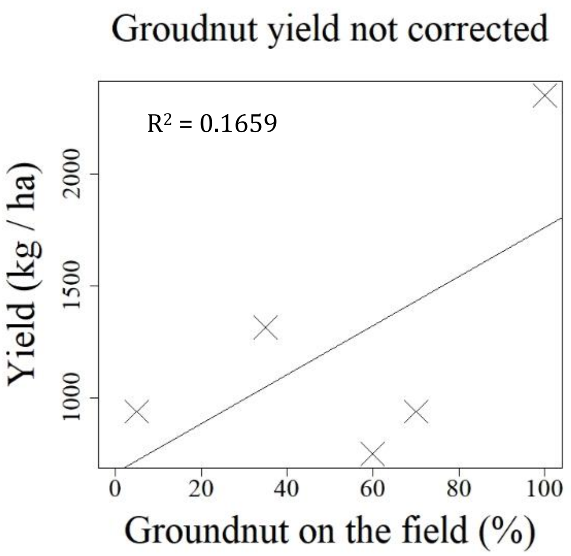
Table III. Relative weight per livestock type. From Stadler et al., 2016.

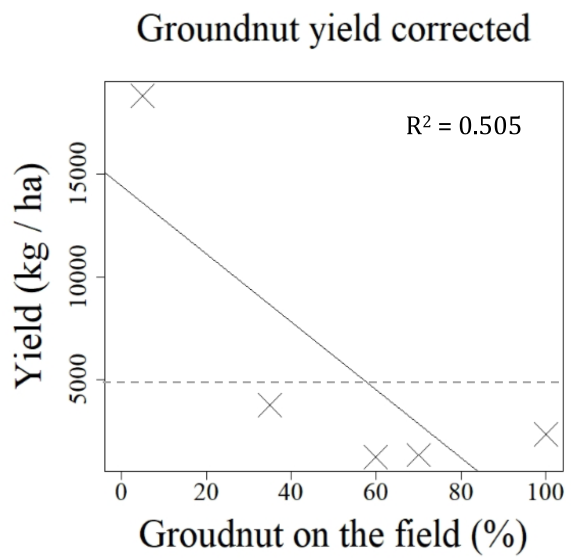
Livestock type	Relative weight
Cattle	0.7
Goat / Sheep	0.1
Ox	0.8
Pig	0.2
Poultry	0.01

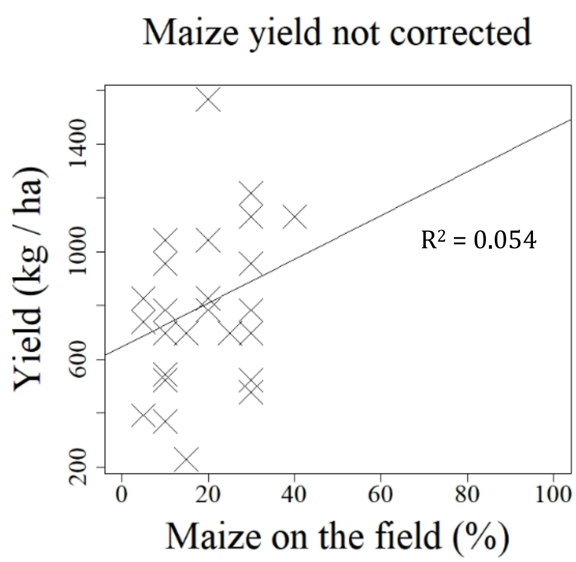
Appendix IV – Intercropping percentages

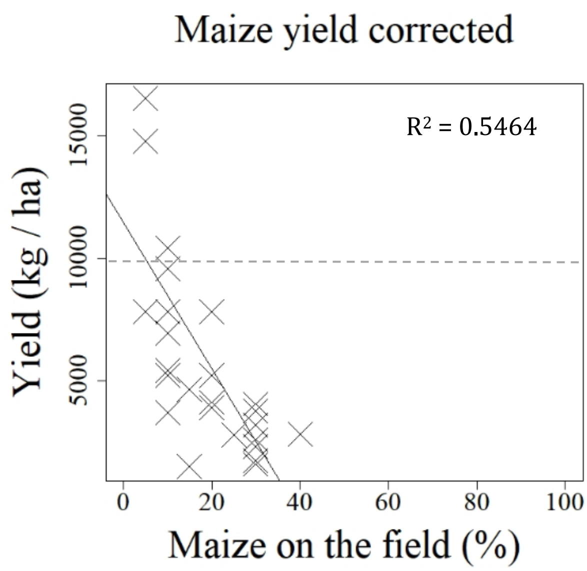












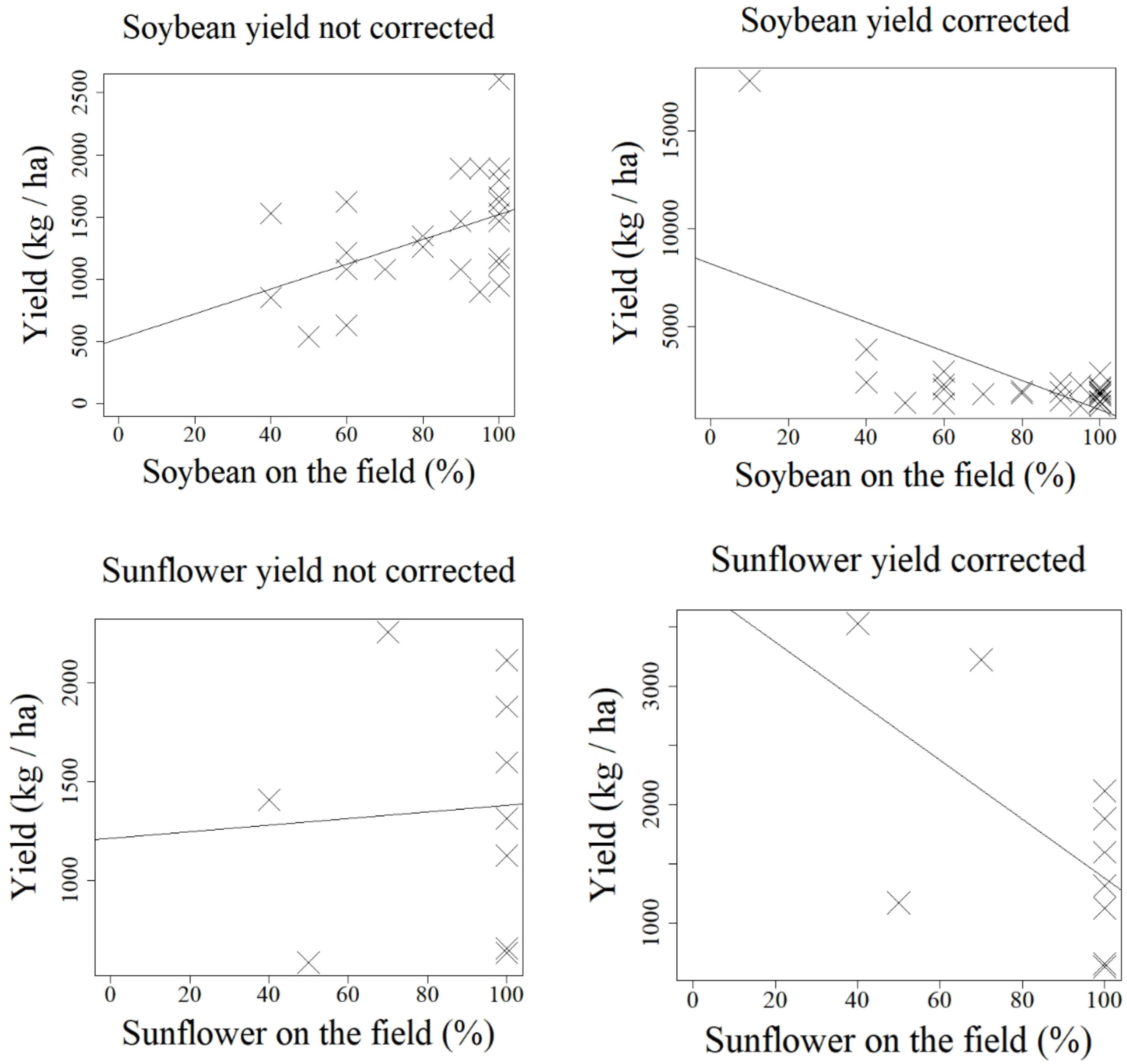


Figure IV. Yields uncorrected and corrected for intercropping fractions with the percentage of the crop on the field.

Appendix V – Grain moisture content

Table V. Average grain moisture content.

Crop	Average grain moisture content (%)	Source
Bean	10	NRCS USA
Groundnut	6	Penning de Vries et al., 1983
Maize	13	Penning de Vries et al., 1983
Millet	10	Penning de Vries et al., 1983
Sesame	6	Penning de Vries et al., 1983
Sorghum	10	Penning de Vries et al., 1983
Soybean	10	NRCS USA
Sunflower	6	Penning de Vries et al., 1983

Appendix VI – Seed weight

Table VI. Number of seeds per gram.

Crop	Seeds g^{-1}	Source
Soybean	9.5	Jones, 2003
Maize	3.0	Jones, 2003
Groundnut	2.0	Jones, 2003
Bean	2.5	Duke, 1983
Cotton	8.0	Jones, 2003
Sunflower	13.0	Robinson et al., 1967
Pea	4.5	Duke, 1981
Sorghum	33.0	Jones, 2003

Seed requirement of sorghum for a hectare is around 5 kg. From:

http://www.arc.agric.za/arc-gci/Fact%20Sheets%20Library/Sorghum%20Production.pdf

Seed requirement of sesame for a hectare is around 3.3 kg. From:

http://baylor.agrilife.org/files/2011/05/sesamegrowerguide2008.pdf

Seed requirement of millet for a hectare is around 2 kg.

http://baylor.agrilife.org/files/2011/05/sesamegrowerguide2008.pdf

Appendix VII – Seed prices

Table VII. Seed prices according to farmers in Oyam. These are the prices in the beginning of the growing season, in other periods of the year can be different.

Seed type	Average seed cost (USD kg^{-1})	Number of informants (n)
Soybean (improved)[1]	1.18	4
Soybean (regular)	0.64	10
Maize (improved)[2]	2.45	7
Maize (regular)	0.26	2
Groundnut	1.47	4
Cassava[3]	0.00	16
Bean	0.49	4
Sesame	1.43	4
Cotton	0.52	2
Sunflower	13.74	5
Pea	0.46	1
Sorghum	0.66	1

[1] Seed costs for improved soybean varieties include 3 unknown varieties and 1 NAM2.
[2] Seed costs for improved maize varieties include 4 unknown varieties, two DK varieties and one Longa 5.
[3] For cassava only stakes are used, which are always free.

Appendix VIII – Grain prices

Table VIII. Average grain prices according to farmers in Oyam. These are the prices shortly after the harvest, in other periods of the year this can be different.

Crop	Grain price (USD kg^{-1})	Number of informants (n)
Soybean (low)	0.27	14
Soybean (high)	0.36	14
Groundnut (unshelled)	0.98	3
Maize	0.16	14
Cassava (dried)	0.15	5
Bean	0.36	11
Sesame	0.76	5
Sunflower	0.28	3
Cotton	0.33	2
Pea	0.38	2
Sorghum	0.26	1

Appendix IX – Consecutive crops

Table IX. Consecutive crops grown on all fields. The main crops of the first and second growing season of 2017, and the first growing season of 2018.

Crop 2017A	Crop 2017B	Crop 2018A	Occurrence
Unknown	Bean	Fallow	1
Banana	Sorghum	Soybean	1
Bean	Sorghum	Fallow	1
Bean	Soybean	Soybean	1
Bean	Soybean	Sunflower	1
Bean	Sunflower	Bean	1
Bean	Sunflower	Soybean	2
Bean	Sunflower	Sunflower	1
Cassava	Cassava	Cassava	4
Cassava	Cassava	Fallow	1
Cassava	Cassava	Sesame	1
Cassava	Cassava	Soybean	1
Cassava	Cassava	Sunflower	2
Cotton	Cotton	Cassava	1
Cotton	Cotton	Soybean	2
Cotton	Cotton	Sunflower	1
Fallow	Cotton	Bean	1
Fallow	Cotton	Fallow	1
Fallow	Cotton	Groundnut	1
Fallow	Cotton	Soybean	2
Fallow	Fallow	Bean	1
Fallow	Fallow	Cassava	1
Fallow	Fallow	Fallow	3
Fallow	Fallow	Soybean	3
Fallow	Soybean	Cassava	2
Fallow	Soybean	Fallow	1
Fallow	Soybean	Sesame	1
Fallow	Sunflower	Pea	2
Fallow	Sunflower	Soybean	1
Fallow	Sweet potato	Groundnut	2
Fallow	Sweet potato	Sorghum	1
Maize	Maize	Bean	1
Maize	Maize	Fallow	1
Maize	Maize	Soybean	2
Pea	Pea	Cassava	2
Pea	Pea	Fallow	2
Pea	Pea	Soybean	2
Pea	Pea	Sunflower	1
Sesame	Soybean	Soybean	1
Sorghum	Sorghum	Soybean	1
Soybean	Fallow	Fallow	3
Soybean	Local vegetable	Sunflower	1
Soybean	Maize	Soybean	5
Soybean	Maize	Sunflower	1
Soybean	Pea	Bean	1
Soybean	Sesame	Fallow	1
Soybean	Sorghum	Soybean	5
Soybean	Soybean	Bean	1
Soybean	Soybean	Cassava	1
Soybean	Sunflower	Soybean	2
Soybean	Sunflower	Sunflower	2
Sunflower	Maize	Sunflower	1
Sunflower	Sorghum	Sunflower	1

Appendix X – Soil characteristics

Table X-a. Average soil characteristics for fields from farmers from the three different farm types. Letters indicate the significance of the difference between the values per column.

Farm type	*n*	pH	OC g kg^{-1}	Total N g kg^{-1}	P mg kg^{-1}	K mmol kg^{-1}	Mg mmol kg^{-1}	Ca mmol kg^{-1}	CEC mmol kg^{-1}	Sand %	Clay %	Silt %
LA-ML	2	6.1 a	32 ab	1.36 ab	7.5 a	7.0 a	10.4 a	42.0 a	142 a	59 a	27 a	14 a
MA-HL	3	6.1 a	19 a	0.80 a	11.3 a	7.0 a	6.8 a	32.1 a	105 a	56 a	29 a	15 a
SA-LL	4	6.1 a	34 b	1.46 b	8.5 a	7.8 a	11.4 a	44.9 a	151 a	47 a	34 a	19 a

Table X-b. Average soil characteristics for fields in the same subcounty. The average of all fields is given below.

Subcounty	*n*	pH	OC g kg^{-1}	Total N g kg^{-1}	P mg kg^{-1}	K mmol kg^{-1}	Mg mmol kg^{-1}	Ca mmol kg^{-1}	CEC mmol kg^{-1}	Sand %	Clay %	Silt %
Acaba	2	6.0	25	1.15	10.5	7.6	9.6	33.0	123	59.6	12.7	27.7
Otwal	2	6.2	20	0.86	9.5	6.2	7.0	31.4	101	51	21	28
Loro	3	6.0	34	1.43	8.3	7.5	12.1	46.0	160	52	16.5	31.5
Minakulu	2	6.4	33	1.34	9.0	8.2	8.6	46.5	137	50	15	35
Total	9	6.1	28.7	1.22	9.2	7.4	9.6	40.0	13.4	53	16	31

Table X-c. Average soil characteristics per crop type allocated to the field in season 2018A.

Main crop	*n*	pH	OC g kg^{-1}	Total N g kg^{-1}	P mg kg^{-1}	K mmol kg^{-1}	Mg mmol kg^{-1}	Ca mmol kg^{-1}	CEC mmol kg^{-1}	Sand %	Clay %	Silt %
Soybean	4	6.0	23	1.00	9.3	6.5	8.5	32.7	116	53	18	29
Non-legumes[1]	4	6.2	36	1.52	8.5	8.2	11.4	46.7	155	53	15	32

[1] Two fields with cassava and two fields with sunflower as main crop.

Appendix XI – Labour requirements

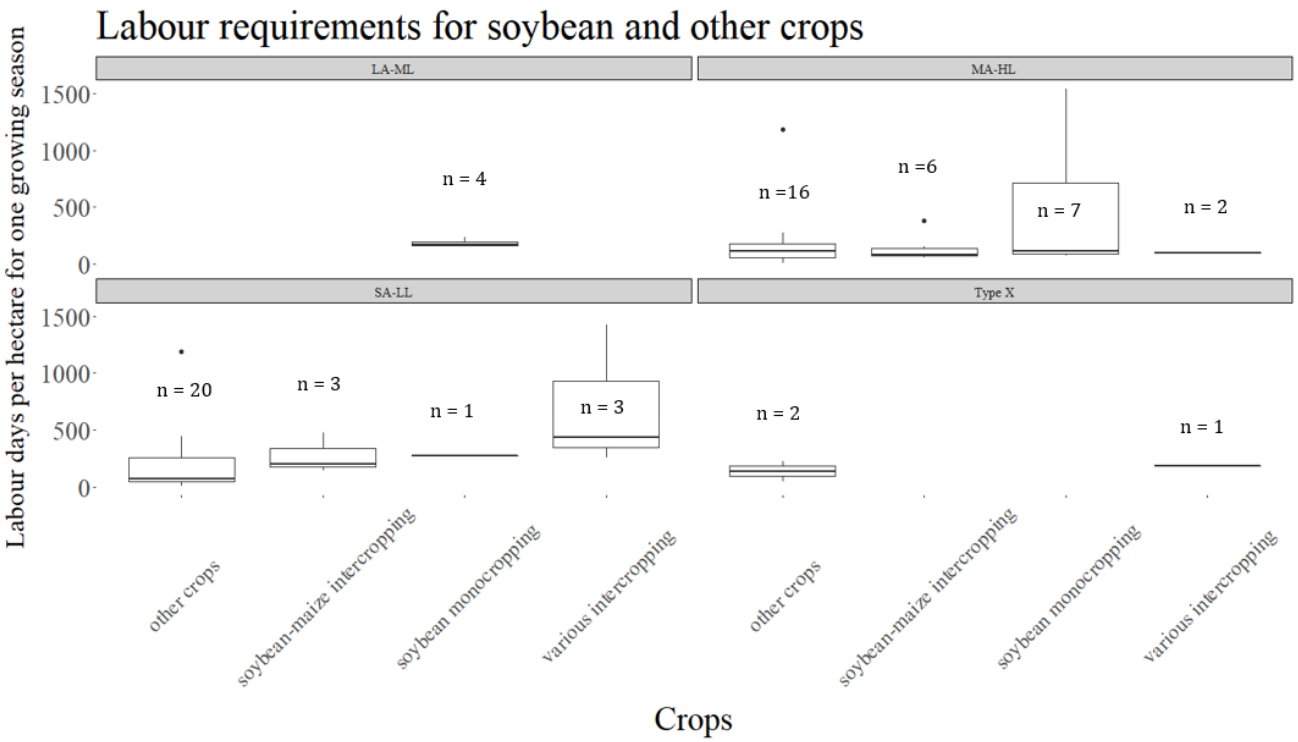


Figure XI-a. Labour use on fields with soybean as single crop, soybean intercropped with maize, soybean intercropped with various other crops and other crops of farm types LA-ML, MA-HL, SA-LL and Type X.

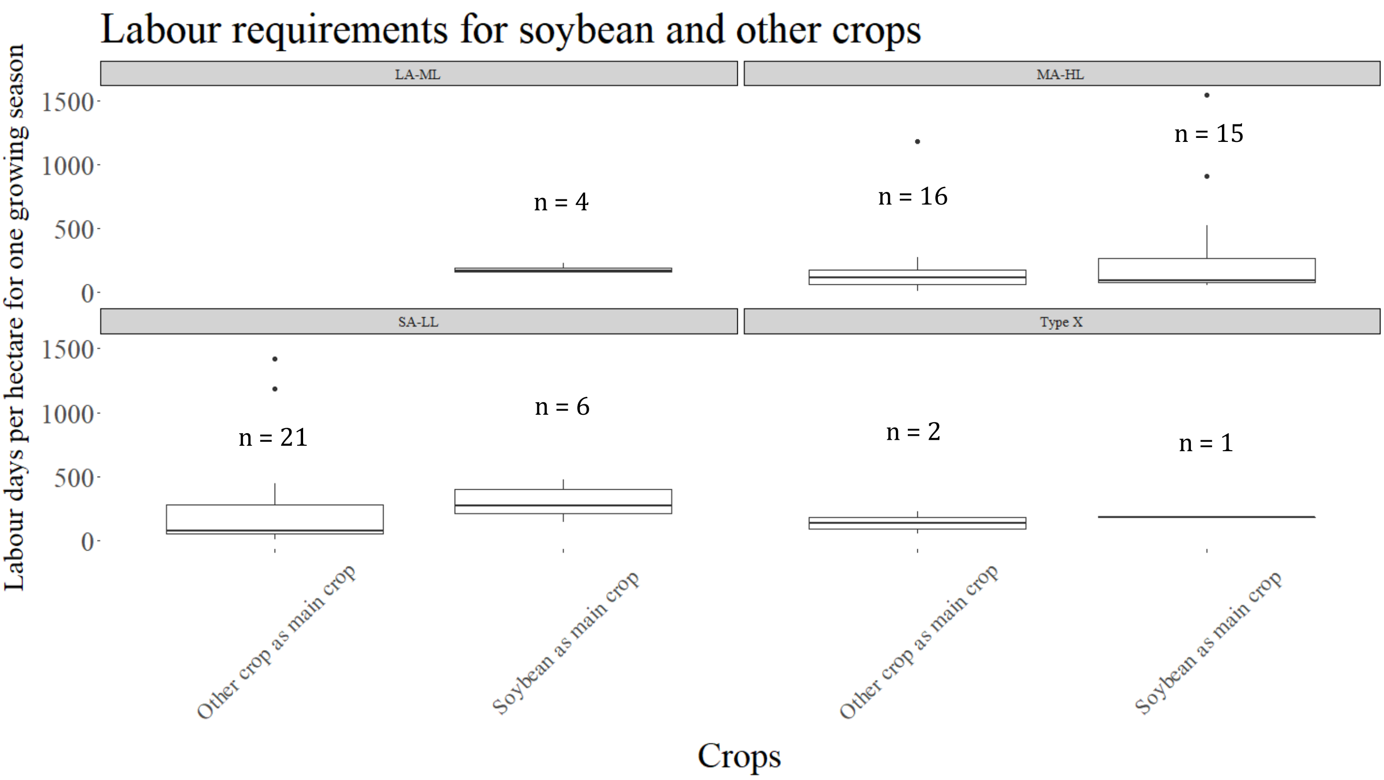


Figure XI-b. Labour use on fields with soybean as a main crop and other crops as main crop in 2018A in farm types LA-ML, MA-HL, SA-LL and Type X.

Appendix XII – Rainfall

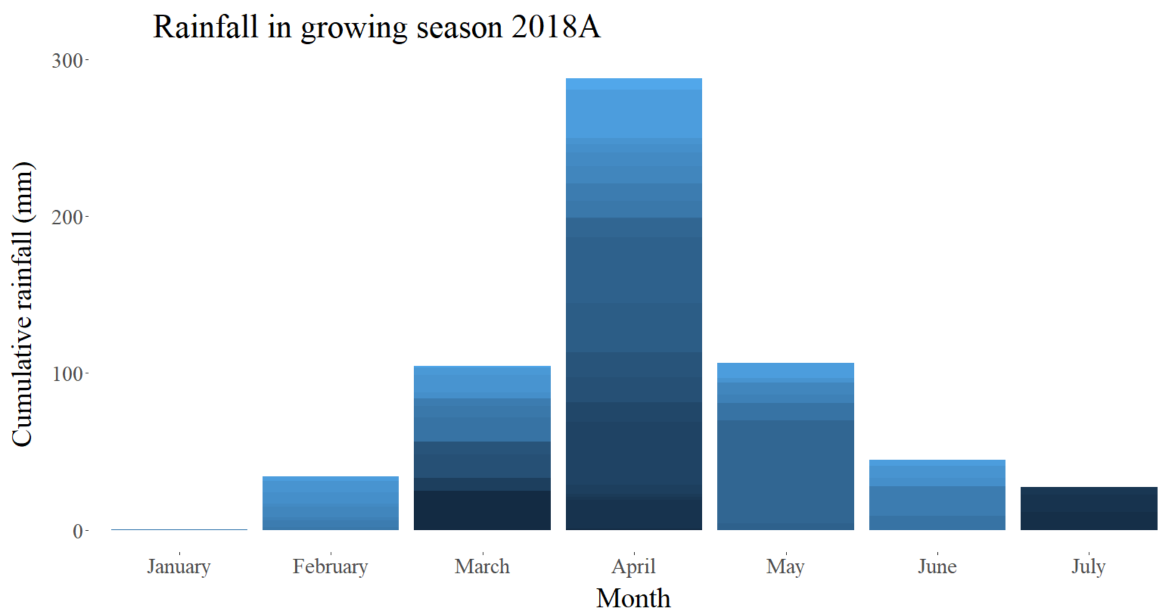


Figure XII. Rainfall in Oyam, measured from January 1st until July 8 . Source: N2Africa.

Appendix XIII – Economic analysis

Table XIII. Economic analysis on crop, field and farm level. The gross margin per crop is the product of the yield and the selling price for crop, with the seed costs subtracted. The gross margin per field is the sum of the income from all crops on the field, with the labour and biocide inputs subtracted. The gross margin on field level is calculated by adding up the gross margin of all fields. * indicates a missing value. Sums are still calculated with missing values, but profit per field is indicated with a * if data is missing. Home consumption is not taken into account, so the profit is not necessarily cash income for the farmers.

Crop												**Field**					**Farm**
Farm ID	**Field ID**	**Field size (ha)**	**Crop**	**Fraction**	**Variety**	**Seed costs per kg**	**Seed costs per field (USD)**	**Yield (kg DM/ha)**	**Selling price (USD/kg)**	**Income per crop (USD)**	**Gross margin per crop (USD)**	**Income per field (USD)**	**Labour costs (USD)**	**% Hired**	**Biocide costs (USD)**	**Gross margin per field (USD)**	**Gross margin from cropping per farm (USD)**
LA-ML_a	So1	1.69	Soybean	1	Improved	1.18	39.46	1890	0.32	1010.66	971.20	971.2	105.79	99	5.49	859.92	3193.30
LA-ML_a	So2	1.16	Soybean	1	Improved	1.18	27.13	1530	0.32	562.47	535.34	535.3	87.94	97	3.77	443.63	
LA-ML_a	So3	0.80	Soybean	1	Improved	1.18	18.61	1530	0.32	385.91	367.30	367.3	54.20	95	0	313.11	
LA-ML_a	So4	2.17	Soybean	1	Improved	1.18	50.60	2610	0.32	1789.71	1739.11	1739.1	155.43	95	7.04	1576.65	
LA-ML_b	SoB1	0.42	Bean	0.5	Regular	0.49	10.23	2160	0.36	161.81	151.57	220.5	0.00	0	0	220.46	2253.45
LA-ML_b	SoB1	0.42	Soybean	0.5	Regular	0.64	2.05	1080	0.32	70.93	68.89						
LA-ML_b	SoBM1	0.75	Banana	0.1	Regular	0.00	0.00	0	0.00	0.00	0.00	403.9	0.00	0	0	403.94 *	
LA-ML_b	SoBM1	0.75	Maize	0.1	Regular	0.26	0.04	7830	0.16	96.12	96.08						
LA-ML_b	SoBM1	0.75	Soybean	0.8	Improved	1.18	13.10	1688	0.32	320.96	307.86						
LA-ML_b	Su1	0.76	Sunflower	1	Regular	13.74	16.83	1598	0.28	346.85	330.03	330.0	0.00	0	0	330.03	
LA-ML_b	Su2	2.65	Sunflower	1	Regular	13.74	116.75	1880	0.28	1415.77	1299.02	1299.0	0.00	0	0	1299.02	
MA-HL_a	BM1	0.11	Bean	0.7	Regular	0.49	7.63	1286	0.36	35.92	28.29	42.4	84.95	82	0.36	-42.91	1957.82
MA-HL_a	BM1	0.11	Maize	0.3	Regular	0.26	0.04	2610	0.16	14.15	14.11						

MA-HL_a	Ca1	0.38	Cassava	1	Regular	0.00	0.00	5040	0.15	289.11	289.11	289.1		56.27	100	0	232.84		
MA-HL_a	Fal1	0.88	Fallow	1	Regular	0.00	0.00	0	0.00	0.00	0.00	0.0		43.26	100	0	-43.26		
MA-HL_a	G1	0.89	Groundnut	1	Regular	1.47	162.36	2350	0.98	2045.06	1882.69	1882.7		84.95	82	2.87	1794.87		
MA-HL_a	SiMi1	0.14	Millet	0.1	Regular	0.50	0.01	3150	0.50	22.21	22.20	141.7		34.77	100	0	106.96		
MA-HL_a	SiMi1	0.14	Simsim	0.9	Regular	1.43	0.60	1253	0.76	120.13	119.53								
MA-HL_a	So1	0.08	Soybean	1	Improved	1.18	1.76	1170	0.32	31.38	29.62	29.6		84.95	82	0.28	-55.61		
MA-HL_a	So2	0.14	Soybean	1	Improved	1.18	2.99	1170	0.32	53.34	50.35	50.4		84.95	82	0.47	-35.07		
MA-HL_a	So3	0.25	Soybean	1	Regular	0.64	3.75	1125	0.32	88.79	85.04	85.0		84.95	82	0			
MA-HL_b	So3	0.37	Soybean	1	Improved	1.18	13.52	1800	0.32	212.01	198.49	198.5		0.00	0	0	198.49		1240.21
MA-HL_b	So4	0.45	Soybean	1	Improved	1.18	9.38	1665	0.32	237.97	228.60	228.60		0.00	0	0	228.60		
MA-HL_b	SoM1	0.76	Maize	0.05	Regular	0.26	0.08	4060	0.16	25.19	25.11	464.30		0.00	0	0	464.30		
MA-HL_b	SoM1	0.76	Soybean	0.95	Improved	1.18	14.98	1989	0.32	454.20	439.22								
MA-HL_b	SoM2	0.90	Maize	0.1	Regular	0.26	0.20	4060	0.16	59.45	59.25	348.80		0.00	0	0	348.80		
MA-HL_b	SoM2	0.90	Soybean	0.9	Improved	1.18	16.74	1200	0.32	306.28	289.54								
MA-HL_c	BCM1	0.14	Bean	0.4	Regular	0.49	8.55	3375	0.36	70.45	61.90	123.90	*	0.00	0	0	123.90	*	356.03
MA-HL_c	BCM1	0.14	Cassava	0.3	Regular	0.00	0.00	5040	0.15	33.34	33.34								
MA-HL_c	BCM1	0.14	Maize	0.3	Regular	0.26	0.10	4060	0.16	28.78	28.68								
MA-HL_c	Fal1	0.18	Fallow	1	Regular	0.00	0.00	0	0.00	0.00	0.00	0.0		0.00	0	0	0.00		
MA-HL_c	So1	0.22	Maize	0.2	Regular	0.26	0.10	7830	0.16	55.54	55.45	133.70		0.00	0	0	133.70		
MA-HL_c	So1	0.22	Pea	0.2	Regular	0.46	0.09	400	0.38	6.62	6.53								

MA-HL_c	So1	0.22	Soybean	0.6	Improved	1.18	2.43	1800	0.32	74.19	71.76								
MA-HL_c	SoCM1	0.17	Cassava	0.3	Regular	0.00	0.00	5040	0.15	39.55	39.55	98.4		0.00	0	0	98.38		
MA-HL_c	SoCM1	0.17	Maize	0.3	Regular	0.26	0.11	1595	0.16	13.41	13.30								
MA-HL_c	SoCM1	0.17	Soybean	0.4	Regular	0.64	0.87	2138	0.32	46.40	45.53								
MA-HL_d	Fal1	0.26	Fallow	1	Regular	0.00	0.00	0	0.00	0.00	0.00	0.0		0.00	0	0	0.00		228.21
MA-HL_d	PCBM1	0.34	Bean	0.1	Regular	0.49	0.25	2130	0.36	26.38	26.12	194.60	*	0.00	0	0	194.60	*	
MA-HL_d	PCBM1	0.34	Cassava	0.35	Regular	0.00	0.00	5040	0.15	92.30	92.30								
MA-HL_d	PCBM1	0.34	Maize	0.2	Regular	0.26	0.23	5220	0.16	58.53	58.30								
MA-HL_d	PCBM1	0.34	Pea	0.35	Regular	0.46	0.46	400	0.38	18.31	17.85								
MA-HL_d	Pea1	0.23	Pea	1	Regular	0.46	1.03	400	0.38	34.67	33.63	33.63		0.00	0	0	*		
MA-HL_e	BM1	0.15	Bean	0.7	Regular	0.49	8.91	1929	0.36	71.93	63.01	79.7		0.00	0	0	79.68		1082.72
MA-HL_e	BM1	0.15	Maize	0.3	Regular	0.26	0.12	2320	0.16	16.79	16.67								
MA-HL_e	Fal1	0.26	Fallow	1	Regular	0.00	0.00	0	0.00	0.00	0.00	0.0		0.00	0	0	0.00		
MA-HL_e	SoM1	0.14	Maize	0.3	Regular	0.26	0.09	3190	0.16	22.58	22.49	69.6		0.00	0	0	69.65		
MA-HL_e	SoM1	0.14	Soybean	0.7	Improved	1.18	2.20	1543	0.32	49.36	47.16								
MA-HL_e	Su1	0.67	Sunflower	1	Regular	13.74	14.67	1457	0.28	275.67	261.00	261.00		0.00	0	0	261.00		
MA-HL_e	Su2B	0.99	Bean	0.05	Regular	0.49	4.07	2130	0.36	38.05	33.99	403.5		0.00	0	0	403.50		
MA-HL_e	Su2B	0.99	Sunflower	0.95	Regular	13.74	20.76	1457	0.28	390.30	369.54								
MA-HL_e	SuBM1	0.29	Bean	0.4	Regular	0.49	6.95	2925	0.36	123.94	117.00	268.9		0.00	0	0	268.87		
MA-HL_e	SuBM1	0.29	Maize	0.2	Regular	0.26	0.10	3915	0.16	37.55	37.45								
MA-HL_e	SuBM1	0.29	Sunflower	0.4	Regular	13.74	3.46	3525	0.28	117.88	114.42								
MA-HL_f	Fal1	0.43	Fallow	1	Regular	0.00	0.00	0	0.00	0.00	0.00	0.0		0.00	0	0	0.00		1143.67

MA-HL_f	So1	0.58	Maize	0.1	Regular	0.26	0.63	9570	0.16	90.13	89.50	346.3		4.72	27	0	341.62		
MA-HL_f	So1	0.58	Soybean	0.9	Improved	1.18	10.77	1630	0.32	267.60	256.83								
MA-HL_f	So2	0.47	Soybean	1	Improved	1.18	8.45	1467	0.32	215.90	207.45	207.4		20.45	100	0	187.00		
MA-HL_f	So3	0.49	Soybean	1	Improved	1.18	10.21	1620	0.32	252.15	241.94	241.9		14.16	95	0	227.78		
MA-HL_f	SoM4	0.65	Maize	0.2	Regular	0.26	1.42	5220	0.16	110.91	109.48	357.9		14.16	95	0	343.77		
MA-HL_f	SoM4	0.65	Soybean	0.8	Improved	1.18	10.80	1575	0.32	259.24	248.44								
MA-HL_f	SorM1	0.07	Millet	0.5	Regular	0.50	0.03	1260	0.50	22.00	21.97	48.20		4.72	63	0	43.51		
MA-HL_f	SorM1	0.07	Sorghum	0.5	Regular	0.66	0.11	2880	0.26	26.37	26.26								
MA-HL_g	BCM1	0.58	Bean	0.6	Regular	0.49	34.44	2175	0.36	274.23	239.78	407.8		0.00	0	0	407.77		523.50
MA-HL_g	BCM1	0.58	Cassava	0.2	Regular	0.00	0.00	5040	0.15	89.50	89.50								
MA-HL_g	BCM1	0.58	Maize	0.2	Regular	0.26	0.14	4133	0.16	78.62	78.49								
MA-HL_g	Fal1	0.24	Fallow	1	Regular	0.00	0.00	0	0.00	0.00	0.00	0.0		0.00	0	0	0.00		
MA-HL_g	Fal2	0.22	Fallow	1	Regular	0.00	0.00	0	0.00	0.00	0.00	0.0		0.00	0	0	0.00		
MA-HL_g	SoM1	0.40	Maize	0.05	Regular	0.26	0.03	4060	0.16	13.14	13.10	115.70	*	0.00	0	0	115.70	*	
MA-HL_g	SoM1	0.40	Soybean	0.95	Regular	0.64	10.19	947	0.32	112.82	102.63								
SA_LL_a	BSoFa1.1	0.10	Bean	1	Regular	0.49	4.52	1440	0.36	53.61	49.09	49.1		0.00	0	0	49.09		321.81
SA_LL_a	BSoFa1.2	0.11	Maize	0.5	Regular	0.26	0.44	4060	0.16	34.96	34.53	60.7		0.00	0	0	60.70		
SA_LL_a	BSoFa1.2	0.11	Soybean	0.5	Regular	0.64	0.79	1620	0.32	27.02	26.23								
SA_LL_a	BSoFa1.3	0.07	Fallow	1	Regular	0.00	0.00	0	0.00	0.00	0.00	0.0		0.00	0	0	0.00		
SA_LL_a	BSoFa1.4	0.14	Maize	0.5	Regular	0.26	0.58	4060	0.16	46.19	45.61	80.3		0.00	0	0	80.30		
SA_LL_a	BSoFa1.4	0.14	Soybean	0.5	Regular	0.64	1.05	1620	0.32	35.70	34.65								

SA_LL_a	Fal1	0.23	Fallow	1	Regular	0.00	0.00	0	0.00	0.00	0.00	0.0		10.23	100	0	-10.23		
SA_LL_a	So1	0.23	Maize	0.1	Regular	0.26	0.02	5220	0.16	19.27	19.26	151.0		9.05	39	0	141.94		
SA_LL_a	So1	0.23	Soybean	0.9	Regular	0.64	3.44	2100	0.32	135.16	131.72								
SA_LL_b	CG1	0.02	Cassava	0.4	Regular	0.00	0.00	5040	0.15	4.90	4.90	15.0		0.00	0	0	14.96		220.75
SA_LL_b	CG1	0.02	Groundnut	0.6	Regular	1.47	1.76	1253	0.98	11.82	10.06								
SA_LL_b	MG1	0.05	Groundnut	0.7	Regular	1.47	6.16	1343	0.98	44.36	38.20	43.6		0.00	0	0	43.57		
SA_LL_b	MG1	0.05	Maize	0.3	Regular	0.26	0.07	2320	0.16	5.44	5.37								
SA_LL_b	SoC1	0.16	Cassava	0.4	Regular	0.00	0.00	5040	0.15	50.35	50.35	112.6		0.00	0	0	112.62		
SA_LL_b	SoC1	0.16	Soybean	0.6	Regular	0.64	0.69	2025	0.32	62.96	62.27								
SA_LL_b	SoC2	0.05	Cassava	0.6	Regular	0.00	0.00	5040	0.15	24.29	24.29	49.6		0.00	0	0	49.61		
SA_LL_b	SoC2	0.05	Soybean	0.4	Regular	0.64	0.18	3825	0.32	25.50	25.32								
SA_LL_c	BCM1	0.31	Bean	0.1	Regular	0.49	0.76	2130	0.36	23.57	22.81	220.21	*	0.00	0	0	197.40	*	220.21
SA_LL_c	BCM1	0.31	Cassava	0.6	Regular	0.00	0.00	5040	0.15	141.36	141.36								
SA_LL_c	BCM1	0.31	Maize	0.3	Regular	0.26	0.60	3770	0.16	56.65	56.04								
SA_LL_d	SiM1	0.06	Maize	0.3	Regular	0.26	0.03	3190	0.16	9.96	9.93	50.50	*	0.00	0	0	50.50	*	419.06
SA_LL_d	SiM1	0.06	Simsim	0.7	Regular	1.43	0.21	1209	0.76	40.82	40.61								
SA_LL_d	Su1	0.50	Sunflower	1	Regular	13.74	11.05	1316	0.28	187.68	176.63	176.6		5.24	51		171.38		
SA_LL_d	SuBG1	0.23	Bean	0.25	Regular	0.49	1.66	2130	0.36	43.14	41.48	197.10	*	0.00	0	0	137.30	*	
SA_LL_d	SuBG1	0.23	Groundnut	0.05	Regular	1.47	2.06	1846	0.98	20.43	18.36								
SA_LL_d	SuBG1	0.23	Sunflower	0.7	Regular	13.74	6.94	3223	0.28	144.23	137.30								
SA_LL_e	Su1	0.22	Sunflower	1	Regular	13.74	9.63	658	0.28	40.86	31.23	31.2		0.00	0	0	31.23		152.33
SA_LL_e	Su2	0.14	Vegetables	0.5	Regular	*	*	*	*	*	*	21.1	*	0.00	0	0	21.12	*	
SA_LL_e	Su2	0.14	Sunflower	0.5	Regular	13.74	2.32	1175	0.28	23.44	21.12								

SA_LL_e	Su3	0.24	Sunflower	1	Regular	13.74	8.29	635	0.28	42.40	34.12	34.1		0.00	0	0	34.12		
SA_LL_e	Su4	0.22	Sunflower	1	Regular	13.74	5.92	1128	0.28	71.78	65.86	65.9		0.00	0	0	65.86		
SA_LL_f	CB1	0.16	Bean	0.5	Regular	0.49	7.87	3060	0.36	88.18	80.31	141.7		0.00	0	0	141.68		347.70
SA_LL_f	CB1	0.16	Cassava	0.5	Regular	0.00	0.00	5040	0.15	61.37	61.37								
SA_LL_f	CBGM1	0.12	Bean	0.15	Regular	0.49	0.88	2130	0.36	13.78	12.90	206.00	*	0.00	0	0	206.00	*	
SA_LL_f	CBGM1	0.12	Cassava	0.35	Regular	0.00	0.00	5040	0.15	32.16	32.16								
SA_LL_f	CBGM1	0.12	Groundnut	0.35	Regular	1.47	7.70	3760	0.98	155.10	147.40								
SA_LL_f	CBGM1	0.12	Maize	0.15	Regular	0.26	0.03	4640	0.16	13.59	13.57								
SA_LL_f	Fal1	0.16	Fallow	1	Regular	0.00	0.00	0	0.00	0.00	0.00	0.0		0.00	0	0			
SA_LL_g	BCM1	0.26	Bean	0.45	Regular	0.49	2.32	1700	0.36	72.34	70.01	187.4		0.00	0	0	187.38		929.80
SA_LL_g	BCM1	0.26	Cassava	0.5	Regular	0.00	0.00	5040	0.15	100.68	100.68								
SA_LL_g	BCM1	0.26	Maize	0.05	Regular	0.26	0.07	7830	0.16	16.76	16.69								
SA_LL_g	BCM2	0.43	Bean	0.25	Regular	0.49	2.63	2520	0.36	96.97	94.35	306.2		0.00	0	0	306.23		
SA_LL_g	BCM2	0.43	Cassava	0.6	Regular	0.00	0.00	5040	0.15	196.67	196.67								
SA_LL_g	BCM2	0.43	Maize	0.15	Regular	0.26	0.70	1523	0.16	15.91	15.21								
SA_LL_g	Ca1	0.43	Cassava	1	Regular	0.00	0.00	5040	0.15	327.16	327.16	327.2		0.00	0	0	327.16		
SA_LL_g	So1	0.38	Soybean	1	Regular	0.64	4.27	945	0.32	113.30	109.02	109.0		0.00	0	0	109.02		
SA_LL_h	BCM1	0.12	Banana	0.05	Regular	*	*	*	*	*	*	76.2	*	0.00	0	0	76.25	*	359.63*
SA_LL_h	BCM1	0.12	Cassava	0.7	Regular	0.00	0.00	5040	0.15	62.96	62.96								
SA_LL_h	BCM1	0.12	Maize	0.25	Regular	0.26	0.03	2784	0.16	13.31	13.28								
SA_LL_h	CMK1	0.17	Cassava	0.6	Regular	0.00	0.00	5040	0.15	78.74	78.74	105.4	*	0.00	0	0	105.40	*	
SA_LL_h	CMK1	0.17	Vegetables	0.3	Regular	*	*	*	*	*	*								
SA_LL_h	CMK1	0.17	Maize	0.1	Regular	0.26	0.04	9570	0.16	26.70	26.66								

SA_LL_h	SM1	0.35	Maize	0.05	Regular	0.26	0.03	4060	0.16	11.47	11.44	178.00	0.00	0	0	178.00	
SA_LL_h	SM1	0.35	Soybean	0.95	Regular	0.64	1.85	1620	0.32	168.39	166.54						
SA_LL_i	Fal1	0.20	Fallow	1	Regular	0.00	0.00	0	0.00	0.00	0.00	0.0	0.00	0	0	0.00	883.27
SA_LL_i	Fal2	0.19	Fallow	1	Regular	0.00	0.00	0	0.00	0.00	0.00	0.0	0.00	0	0	0.00	
SA_LL_i	SoM1	0.35	Maize	0.4	Regular	0.26	0.90	2828	0.16	63.99	63.09	239.6	0.00	0	0	239.55	
SA_LL_i	SoM1	0.35	Soybean	0.6	Regular	0.64	1.04	2700	0.32	177.51	176.46						
SA_LL_i	SoMCB1	0.41	Bean	0.1	Regular	0.49	2.02	2130	0.36	31.44	29.42	337.20	0.00	0	0	337.20	
SA_LL_i	SoMCB1	0.41	Cassava	0.6	Regular	0.00	0.00	5040	0.15	188.59	188.59						
SA_LL_i	SoMCB1	0.41	Maize	0.2	Regular	0.26	0.18	7395	0.16	98.83	98.65						
SA_LL_i	SoMCB1	0.41	Soybean	0.1	Regular	0.64	0.46	1620	0.32	20.97	20.50						
SA_LL_i	Su1	0.55	Sunflower	1	Regular	13.74	21.37	2115	0.28	327.91	306.55	306.5	0.00	0	0	306.55	
SA_LL_j	Fal1	0.58	Fallow	1	Regular	0.00	0.00	0	0.00	0.00	0.00	0.0	22.02	100	0	-22.02	164.95
SA_LL_j	SCM1	0.18	Soybean	0.6	Regular	0.64	0.74	1800	0.32	60.15	59.40	120.0	0.00	0	0	119.98	
SA_LL_j	SCM1	0.18	Cassava	0.3	Regular	0.00	0.00	5040	0.15	40.58	40.58						
SA_LL_j	SCM1	0.18	Maize	0.1	Regular	0.26	0.02	6960	0.16	20.01	19.99						
SA_LL_j	SM1	0.21	Soybean	0.7	Regular	0.64	1.67	1543	0.32	72.27	70.60	88.50	21.50	95	0	67.00	
SA_LL_j	SM1	0.21	Maize	0.3	Regular	0.26	0.14	1740	0.16	18.04	17.90						
X	Fal1	0.72	Fallow	1	Regular	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0	0	0.00	625.23
X	Fal2	0.69	Fallow	1	Regular	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0	0	0.00	
X	BCM1	0.47	Bean	0.5	Regular	0.49	5.79	1440	0.36	122.17	116.38	302.60	14.16	34	0	288.44	
X	BCM1	0.47	Cassava	0.4	Regular	0.00	0.00	5040	0.15	144.54	144.54						
X	BCM1	0.47	Maize	0.1	Regular	0.26	0.08	5438	0.16	41.77	41.69						

X	SoBM1	0.72	Soybean	0.6	Regular	0.64	4.26	1050	0.32	143.44	139.18	336.78	0.00	0	0	336.78
X	SoBM1	0.72	Maize	0.1	Regular	0.26	0.16	3698	0.16	43.47	43.31					
X	SoBM1	0.72	Bean	0.3	Regular	0.49	9.31	2100	0.36	163.60	154.29					

Appendix XIV – Household survey

Part 1: General house and farm characteristics

General information

Meeting the respondent, explaining the research and discussing the farm characterization trajectory.

Household ID[1]	
Date (dd/mm/yyyy)	
District	
Parish	
Village	
Name interviewer	
Homestead GPS code	
Name of the respondent	
Gender	
Age	
Position in the household[2]	
Mobile phone number	
[1]Also add N_2Africa household ID here, if available [2]Choose from: household head, joint household head, spouse of head, other family member, other	

Household characteristics

Household type

Household type[3]	
Number of people in the household[4]	
[3] Choose from: Family with two parents, single/divorced/widowed, spouse works away, other adult in charge, child headed [4] Only include members who live there at least 3 months per year	

Age

Age group	# Male	# Female
0 – 16 years		
17 – 35 years		
36 – 60 years		
Over 60 years		

Education

Indicate the highest level of schooling:

Household head[5]	
Person with the highest education in the household[5]	
[5] Choose from: cannot read or write, can read and write, primary school, secondary school, post-secondary education	

Production orientation

Indicate the percentage or tick below the produced goods used for own consumption and sold:

% Own consumption	
% For market	

0 All products are used for home consumption, nothing is sold
0 Most products are used for home consumption, some is sold
0 Half of the production is used for home consumption, half for the market
0 Most of the production is for the market, some is used for home consumption
0 All is produced for the market

Income sources

Indicate the percentage or tick below the income that comes from farming activities, or off-farm sources

% from farming	
% from off-farm sources	

0 All the income comes from the farm's household
0 Most of the income comes from the farm, a small part from off-farm sources (off farm sources include trade, business, salaried job, casual labour, pension, remittances, etc.)
0 About half of the income comes from the farm, the other half from off-farm sources
0 Most of the income comes from off-farm sources, a small part from the farm
0 All the income comes from off-farm sources

Ranking of sources of farm income to importance, tick important sources of cash income in the first column, then rank to importance.

	Main	Rank
Cropping		
Livestock		
Trade		
Other business		
Pension		
Salaried job		
Remittances		
Casual labour on-farm (work on other people's field)		
Casual labour off-farm		
Other:		

Food security

Indicate the months in which the majority of the food usually comes from the own farm

____

Does the farm household experience periods in which members of the household eat less because of food shortages?

Yes / Yes, sometimes (for example in dry years) / No, never

If yes, in which months can household members eat less due to food shortage?

___

Confirming variables of farm classification

Does the farmer grow soybean? Yes / No

Has the farmer worked with N_2Africa before? Yes / No

What type of tools does the farmer use to work the land?

___

Does the farmer use improved seeds? And are they bought every year or saved at home?

___

Does the farmer use inputs such as pesticides, inoculants and fertilizers?

___

Did the farmer have any training or schooling about farming? If so, what? What is done differently having that knowledge?

___

___

General farm characteristics

Membership farmer group

Is the household head a member of a farmers group/cooperation/etc?

___

If yes, what benefits does it give the farm household?

___

Market access

Which markets does the farmer visit to sell production or buy inputs?

___

How long does it take the farmer to get there? What is the mode of transport? Transport costs?

___

___

Farm size and land ownership

What is the total area of the farm? (farmland used by the household, owned & used)

___ (area & unit)

Has the size of the farm increased or decreased in the past five years? Where did the additional land come from? (e.g. bought, converted from nature?)

___

What percentage of land of the farm is owned by the household?

____

How much land does the farmer own for the different land uses?

Land use	**Land size (+ unit!)**
Cultivated	
Permanent fallow	
Grassland	
Under trees	
Rented out	
Other?	

Is there a home garden? Yes / No

Farm labour

How many people from your household are working on the farm? And then full-time or part-time?

____

Does the farmer hire labour from outside the household to work in the fields?

0 Yes, permanently (i.e. every year, throughout the cropping season)
0 Yes, regularly (e.g. at peak periods during the cropping season)
0 Yes, sometimes (e.g. only if money allows)
0 No, never

Part 2: Cropping and livestock ownership

Crops

Importance of crops

Most important crops of the farmer. Indicate whether the crop is used for sale or home consumption.

#	Crop name (species)	Reason	S/H
1			
2			
3			
4			
5			

Market prices

Crop name (species)	Seed cost (unit!)	Other important costs?	Market price when sold

Soybean cultivation

If the farmer is cultivating soybeans, ask the following questions:

When did the farmer start cultivating soybeans?

____

Why did the farmer start cultivating soybeans?

____

____

Have there been changes in use of e.g. varieties, inputs, labour saving tools (threshers, planters)? What are the reasons for the use (change) of certain varieties, and for (not) using inputs?

____

____

Is soybean used for home consumption/sale?

____

If sold, to whom?

____

How are prices determined?

How reliable is the market?

Is soybean processed into snacks/yoghurt/etc. by the household for consumption or sale?

What are perceived advantages / disadvantages of soybeans?

Livestock

Amounts of livestock

Number of small ruminants and other livestock species owned by the household

Sheep (no.)	
Goats (no.)	
Pigs (no.)	
Donkeys (no.)	
Chicken (no.)	
Other:	

Number of cattle owned: __________

Herd characteristics:

Cattle ID#	Sex (M/F)	Breed (Name breed. If exact breed is unknown: pure/cross/local breed	Age group 1= < 6 months 2 = > 6 months & < 3 years / 1st calving 3 = adult	If male, used as oxen? Y/N
1.				
2.				
3.				
4.				
5.				
6.				
7.				

What are the main reasons for having the animals?

Livestock sale

Animals bought or sold in the last 2 seasons (1 year)

Type (species)	Bought / Sold	# Sold	Price per animal	How sold? (market, farmer, trader, bucher, other)

Were any animals slaughtered for own use? If yes, note number and species

____

When a cow is sold, for what reason?

____

Is there a specific age at which cows are normally sold?

____

Milk production and other regular sales

Are the cows milked? Yes / No

If they are milked, what part of the milk is sold? And for what price is the milk sold? Does this differ per season?

Unit	Rainy season			Dry season		
	Yield/day	Sold/day	Price/unit	Yield/day	Sold/day	Price/unit

Are there any other regular (e.g. daily, weekly, monthly) sales from the animals? For instance eggs? If so, note amount, type and price

____

Livestock costs

Household expenditures on livestock in the last 12 months

Type of input purchased (medicine, concentrate, etc.)	For which livestock	Amount purchased (local units)	Price per local unit	Obtained from (village/local market/urban market/other)

If one of the inputs is bought on a regular basis: more specific information; e.g. how often is this product bought, is it the same throughout the year, etc.

Cattle feeding

In a wet or dry month, what is feed for the cattle? Rank the importance of the different sources, starting with 1 for the most important.

Feed sources (e.g. stover, concentrates, grazing on compound, free grazing/common land):	Rank (wet season)	Rank (dry season)
1.		
2.		
3.		
4.		
5.		
6.		

How is wet defined, and how is dry defined?

____

Cattle housing

Where are the animals kept overnight? In what type of housing?

____

What proportion of the day is spent inside? (0, 25, 50, 75, 100 %)? ____________________

Is this different in the dry and in the rainy season? Yes / No ________________________

Manure management

When the cows are inside, what proportion of the manure is collected? _______________(%)

Where are the cows if they are not inside? E.g. grazing around the homestead, grazing in common land? Note for all the places where they are grazing, the % of time spent and the % of manure collected

Grazing location	Time spent (%)	Manure collected (%)

Is all the manure that is collected stored and put in the field or is it also used for other purposes (e.g. fuel, cement)? Stored / other purposes (indicate proportions)

____

How is the manure stored? Choose from: open heap, compost pit, covered with plastic, direct application to the fields, other

____