Agro-ecological intensification of mixed crop-livestock systems in Bougouni, Southern Mali

Exploring crop intensification options for farmers with different resource endowments

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February 2015

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For quality of life

Agro-ecological intensification of mixed crop-livestock systems in Southern Mali - *Exploring crop intensification options for farmers with different resource endowments*

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Reg. No.: 910106979080

MSc Thesis: PPS-80436

Plant Production Systems Group

February 2015

Wageningen, The Netherlands

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Preface

This thesis is presented as part of my master's degree in Organic Agriculture, with a specialization in Agroecology, at the Wageningen University, The Netherlands. This research has been done under the supervision of Plant Production Systems chair group from August 2014 to February 2015. This research was executed in Bougouni, Southern Mali during the period between 21st August and 20th November in 2014, and the thesis report writing took place afterwards in Wageningen.

The data for the typology making was gathered from my local supervisor through the *International Crops Research Institute for the Semi-Arid-Tropics* (ICRISAT), and this data set was originated from the survey executed in the Bougouni region by Compagnie Malienne pour le Développement des Textiles (CMDT) in 2013. The information and data for the cotton production and profits analyses was mainly collected from the survey carried out in three AfricaRISING villages (Dieba, Flola and Sibirila) in the Bougouni region in October and November 2014. The information and data for the crop trials was also gathered from my local supervisor, and the crop trials were executed from May to December 2014 in four AfricaRISING villages (Dieba, Flola, Madina and Sibiriala) in the same region.

Acknowledgements

"Life is not so short but that there is always time for courtesy"

-Ralph Waldo Emerson

In retrospect, there were things happened during the last six months in an expected and unexpected way. If my thesis is like a marathon, then the first three months are a process of overcoming physical constraints and the second three months are a process of overcoming mental constraints. It will be nearly impossible to complete this marathon course without all your help and support.

First of all, my deepest gratitude goes to my supervisors Katrein Descheemaeker and Mary Ollenburger. I have been incredibly lucky to meet Katrien, who provides me with this thesis opportunity to explore the farming practices in this ancient and mysterious continent. I am indebted to Katrien for her invaluable guidance, assistance, inspirations and kind considerations for my daily life and studies as well as her word-by-word corrections of the major and minor grammar mistakes I have made. She also spares no effort to instructing me in her working time and private time. She spends one hour every week in discussing the progress of my report, and revising my draft report during her holiday. I would also like to give my earnest thanks to her for kindly tolerating my inappropriate personal expressions and behavior. And I give thanks, very sincere thanks, to Mary. I still remembered that she stood and waited at the outside of the terminals for nearly two hours at midnight due to the issue of undelivered package on the first day of my arrival. I am grateful to Mary, who contributes enormous amount of time to assisting me in purchasing the necessities and providing instructions on my interview and other invaluable contributions. I would also like to thank Katrien and Ken together, for your invaluable visits and unforgettable dinner in Bougouni. Also, I would like to thank Stephanie for guiding me through the process of principal component analysis and cluster analysis, and thank Ivan for teaching me the principle of boundary line analysis. A special thank goes to Argyris for discussing the constraints of profits analyses. I would also like to thank Gatien for providing valuable information and data regarding profits analyses of the crop trials.

I am indebted to lots of people I met during my staying in Bougouni. At first, I would like to thank an anonymous local Malian, who heard about my embarrassing economic situation at the hotel and warmly took me to the local banks allowing MasterCard transactions. This endeavor relieved my burden to a large extent. I am grateful to Mobiom staff for their warmly invitations and hospitality and allowing me to stay in the meeting room occasionally. I greatly appreciated the help of Mary and the Mobiom staff who facilitated the vehicle for me during my staying in Bougouni. I greatly enjoyed working with the technicians (Boire and Goita), contact persons (Adama, Basseriba and Fousseyni) and mostly rural farmers who participated in the survey in each village, who made me feel welcome. I would also like to thank translator Alpha, Momoni and Yaodiouma for translating the Malian into English for me. I am also grateful to Mobiom staff and farmers who warmly made the tea for me. It was such a pleasure for me to meet these farmers. They allowed me to grasp a glimpse into their daily lives in such difficult circumstances.

Last but not least, I would like to thank *Mcknight Foundation* for funding my travel tickets and translation fees.

Youfei Xu

Table of contents

Abstract

In the Bougouni region of Southern Mali, the farming system is dominated by small-scale mixed crop-livestock farmers. Agriculture remains rainfed with a highly erratic rainfall during the rainy season. Farmers grow food crops such as maize, sorghum and millet combined with cash crops such as cotton. Cotton plays a key role in both farmer's livelihood and the regional economy, as it serves as a main approach for farmers to get access to inputs such as chemical fertilizers. Also, rice and groundnut are grown by farmers for the purpose of sales and household food consumption.

A high population growth rate of 3% combined with low crop and livestock productivity poses a challenge for the regional development, although the fallow lands are abundant in this region. In order to address this challenge, agro-ecological intensification is proposed as a feasible approach. Different options have been tested in Mali and other similar contexts and the experimental results are promising in terms of increasing crop productivity, while actual adoption of these practices by farmers is rather limited. One of the main reasons for this is that experimental results fail to account for constraints arising at the farm or even higher levels. Also, the implementation of agro-ecological intensification options fails to take into account the enormous diversity in smallholder farms.

The objective of this thesis is to derive a farm typology based on farm structural characteristics in Bougouni, and to analyze the profitability of agro-ecological intensification practices by utilizing a farm typology mainly focusing on cotton production. Then, the effects of various intensification options on the grain and fodder yields increase potential tested by on-farm trials are also addressed in this study.

To do so, a farm typology was constructed based on the survey data of 162 households in four villages in the Bougouni region. Five farm types were identified in this study, ranging from type 1 farmers with large resource endowments to type 5 farmers with fewer resources. A farm-type specific gross margin analysis of the cotton production was presented in this paper. As regards to the net income of the organic cotton on a per hectare basis, farm type 5 was able to achieve more profits compared to the farmers of other types when proper management was done, e.g., timely weeding. For the conventional cotton, farm type 1 achieved the highest net income, while farm type 4 got the highest net income per family worker.

Participatory on-farm trials were conducted in four villages to test a basket of agro-ecological intensification options, including judicious application of chemical fertilizers in combination with compost, improved hybrid variety combined with bio-pesticides, seed inoculation combined with compost application, two intercropping arrangements combined with improved hybrid variety. The trial results suggest that the application of chemical fertilizers could significantly increase maize grain yields compared to non-fertilization ($P<0.05$). The improved fodder variety could significantly increase the cowpea haulms yields compared to the local variety ($P<0.05$). The land use advantage of intercropping with the additive and replacement design over the sole cropping was evident ($LER>1$).

Farm typology indeed provided a structural entry point for analyzing the profitability of the cotton production in the context of Southern Mali. Conventional cotton was more profitable than organic cotton on a per hectare basis for farm type 1 to 4 mainly due to the lower yields of the latter. Intensification options such as judicious chemical fertilizer application, adoption of the improved fodder variety and intercropping proved to be applicable in the context of Southern Mali.

1. Introduction

1.1 The Context of Mali

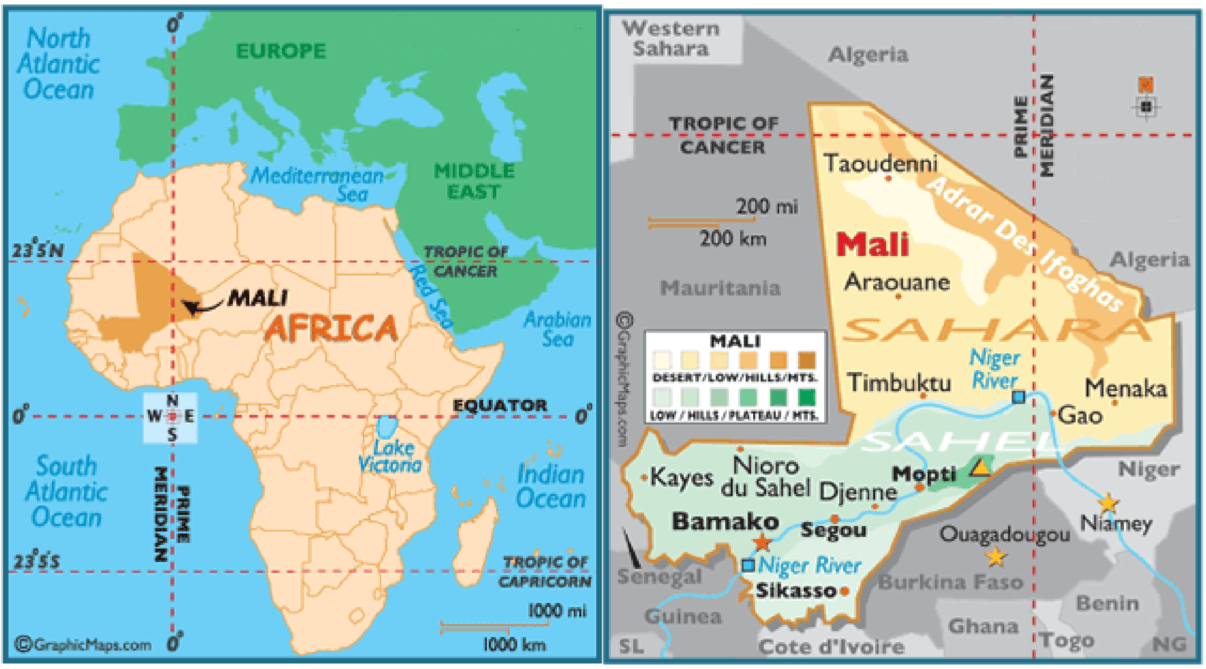

Figure 1. Location of Mali by coordinates in Africa (left) and physical map of Mali (right)
source:(WorldAtlas, n.d.)

Mali is a landlocked country located in West Africa, lying from 10°, 13°W to 25°N, 5°E (Coulibaly, 2006). Among the total land area of 1,240,190 km^2, 7% is occupied by arable land, and 12% by forests (FAOSTAT, 2014). The country has four major climatic zones, ranging from the south to the north, including Guinean, Sudanese, Sahelian and Saharan zone (Coulibaly, 2006). In Mali, the seasonal weather cycle consists of three different periods (Lélé & Lamb, 2010). The rainy season occurs from June to October. The cold season is between October and February, followed by the extremely hot and dry season until June (Lélé & Lamb, 2010). In addition, the climate also differs greatly from the south to the north. In the Guinean zone, the average annual rainfall is over 1300 mm with an average daytime temperature of 28°C while the annual rainfall is less than 150 mm with an average daytime temperature over 35°C in the Saharan zone (Lélé & Lamb, 2010).

In 2013, the estimated total population of Mali was 15,302,000, of whom 90% lived in the southern region close to the Niger and Senegal rivers (UN, 2013). Rural households account for 63% of the total populations (FAOSTAT, 2014). The largest ethnic group of Mali is the Mande (Bambara, Malinke, Soninke), making up 50% of the total population (UN, 2013).

The agriculture sector is the backbone of Mali's industry with 73% of the total labor force engaged in agricultural activities and contributing 42% of Malian Gross Domestic Product (GDP) (FAOSTAT, 2014). Small-scale traditional farming dominates the agriculture sector on 90% of total area under cultivation (TAP for Cotton, 2012). Crops grown for domestic consumption comprise maize, rice, sorghum, millet and cash crops for export include cotton, sesame, groundnut (FAOSTAT, 2014).

Cotton, the main cash crop, known as "white gold" and "the mother of poverty", is a strategic productive sector in Mali (Benjaminsen et al., 2010). This sector not only provides a capital source for elites (politicians and bureaucrats) but also a crucial income source for smallholder farmers (Serra, 2012). Except for part of the supply chain of the organic cotton, the cotton sector is managed by a parastatal company, Compagnie Malienne pour le Développement des Textiles (CMDT). What distinguishes cotton from other crops is that it represents the main source of livelihood for about one quarter of the Mali's population and 50% of the Gross National Product (GNP) (Tappan & McGahuey, 2007). The benefits of cotton are noticeable and pervasive. Cotton not only serves as an income generating engine for the agriculture sectors but it also spills over to other sectors managed by CMDT, covering education, medical care, infrastructure development in rural area, such as schools construction, farmers' literacy classes, health centers, wells, road maintenance (Serra, 2012). As such, over time it has built up a basis for the farmers to get access to fertilizers, chemicals and equipment rather than just being a relevant economic sector (Serra, 2012). Lately however, CMDT has gradually withdrawn the support for the rural development listed above while the village cooperatives still remain as a powerful existence (Theriault & Tschirley, 2014).

1.2 Problem Definition and Rationale

Africa has the highest population growth rate over the past three decades among all continents and Mali is no exception to this (UN, 2013). In 1980, the total population of Mali was 6,735,000; thirty years later, the total population rose to 13,986,000 with an annual growth rate of 3% (UN, 2013). It is worth noting that arable land only made up 6% of total agricultural land area in 1980, and increased to 15 % in 2010 with an annual growth rate of 3% (FAOSTAT, 2014). However, excluding the area of temporary crops as well as fallow lands, the permanently cultivated land only accounted for 2% of total agricultural land in 2010, which is still quite small (FAOSTAT, 2014). Another striking fact is that the population of Mali is unevenly distributed with 90% of the total population living in the southern region. The agriculture sectors follow the same pattern as the southern regions contributed more than 90% of the total cereal production in 2006 (Kumar, 2013). As population will continue to grow, it is not difficult to discern that both food and feed demands will increase tremendously in Southern Mali for the near future (Nijenhuis, 2013; Poccard-Chapuis et al., 2014).

Generally speaking, coarse grain yields are low, while cotton productivity is one of the highest in West Africa (Abdulai & CroleRees, 2001). Although the cotton yield had increased from 225kg/ha in 1961 to 1200kg/ha in 1990, there has been a decline in the cotton yield since then (Laris et al., 2015). In 2006-2010, the cotton sector had fallen into crisis with mounting fertilizer prices, poorly maintained equipment, inefficient management of the cotton company (CMDT) and farmers' lack of access to credits (Serra, 2012; TAP for Cotton, 2012). Recently, the cotton sector is recovering gradually (Falconnier et al., submitted). Cotton is cultivated in rainfed conditions in Southern Mali, which indicates the yield is affected greatly by erratic rainfall (TAP for Cotton, 2012). In addition, cotton is susceptible to a wide range of insects, thus pesticides and sprayers are indispensable investments for cotton farmers (Cotton Incorporated, n.d.). As for the farmers, whether to engage in the cotton sector is still a dilemma. On the one hand, cotton is a nutrient demanding crop and is vulnerable to insect infestation, thus it relies heavily on fertilizers and pesticides. On the other hand, cotton not only generates cash flow but also provides the access to fertilizers and chemicals for these farmers, so that they can also apply fertilizers to cereal crops such as maize, and to a lesser extent, sorghum and millet (Laris & Foltz, 2014). Recently, CMDT also started to provide subsidized fertilizer for maize and rice, but the credits for cereal fertilizers was calculated based on the cultivated area of the cotton (Fuentes et al., 2011). Thus, the nutrient deficiency for cereal crops is still quite large in comparison to cash crops (Laris & Foltz, 2014; Laris et al., 2015).

The expansion of the livestock sector also poses a challenge to farmers, mainly due to the reduction of rangelands as well as the shortage of palatable forage species over the dry season (Ba et al., 2011; Turner et al., 2014). Apart from the declining pasture and vegetation density, the prevalence of livestock diseases and absence of veterinary care are hitting farmers hard, as livestock are indispensable for farmers' livelihood (Ayantunde et al., 2014). The rising numbers of livestock in Southern Mali might also give rise to more conflicts between farmers and herders, as they have to compete for limited resources such as water during the dry season (Benjaminsen et al., 2010; Turner et al., 2011; Lambin et al., 2014). More than 56% of pastoralists claimed that they had conflicts with local farmers at certain encampments during the rainy season in Southern Mali because of livestock-induced crop damage (Turner et al., 2014).

Agro-ecological intensification is proposed as a solution when addressing the challenges like increasingly high input costs, high food and feed demands, low crop productivity, farmers' vulnerability to institutional configuration (Erenstein, 2006; Pretty et al., 2011; Tittonell & Giller, 2013) Agro-ecological intensification provides an applicable entry point to design a type of farming system that depends less on non-recyclable external inputs and relies more on the functionality of the ecosystem services (Erenstein, 2006; Tittonell & Giller, 2013). For Southern Mali, agro-ecological intensification is more suitable than capital-based intensification due to several facts confronted by those smallholder farmers: low soil fertility with poor response to the input of chemical fertilizers; destructive shifting cultivations that results in unresponsive soils; lack of access to external inputs (de Ridder et al., 2004).

> *"Agro-ecological intensification is a practical, knowledge-based approach with potential to respond both to the needs of smallholder farmers for increased production through more efficient use of local resources and to the demands placed on the high-input export sector for more environmental sustainability. This approach does not exclude the use of external inputs, but focuses on biological mechanisms to suppress pests and diseases, strategies to increase yield and management of soil nutrient cycles for a healthier and more productive crop"* (Côte et al., 2010).

Organic cotton may provide an alternative pathway for smallholder farmers in the context of Southern Mali. It might be able to minimize the adverse impacts of the institutional monopoly and increasingly high cost of inputs while still maintaining the cotton sector's extension and input supply service in rural areas. Since organic cotton production mostly relies on natural capital such as compost[1], input costs can be reduced and farmers become partly independent from CMDT (Kloos & Renaud, 2014). Moreover, the selling price for the organic cotton is higher than for the conventional cotton so that lower organic cotton yields can be compensated to some extent (Leighton & Sacande, 2011). In addition, the organic cotton can be intercropped with vegetables like okra, offering farmers the chance to acquire diversified earnings from one piece of land (FAIRTRADE, 2010). Bassett (2010) referred to several positive effects for farmers in Southern Mali from introducing organic cotton,

[1] In this paper, compost represents composted household wastes, garbage and crop resides.

including more women's participation and improved soil fertility. As a result of the dissemination of organic cotton practices, even the farmers who did not grow organic cotton began to use bio-pesticides and to try integrated pest management. Lakhal et al. (2008) stated that a shift from conventional cotton to organic cotton brings about job opportunities for the regional development and health benefits for the farmers in Mali.

Improved cereal crop varieties can offer smallholder farmers a cost-effective option to overcome the disadvantages of local varieties like low yields and susceptibility to droughts and diseases (ICRISAT, n.d.). However, increasing cereal yield cannot be achieved solely by using improved varieties. Foltz et al. (2012) found that both the adoption of new varieties and the incremental use of chemical fertilizers play a crucial role in increasing maize yields in Southern Mali. Kouyaté & Diallo (2012) showed that legume-sorghum rotation associated with application of green manure and Tilemsi rock phosphate increased sorghum yields and ameliorated the soil fertility with increased soil organic carbon, phosphorus and calcium content. Agronomic practices that combine phosphorus-based fertilizers and seed inoculation show the potential to increase soybean grain yields for low resource endowed farmers (Franke et al., 2014). In addition, soybean residues had a positive effect on the yields of maize grain in the subsequent year (Franke et al., 2014). Bationo et al. (2012) reviewed several studies of legume-cereal intercropping system from Sudanese-Sahelian zone of West Africa and pointed out that this system enhances the long-term yield stability of both crops compared to mono-cropping system.

Although these agronomic practices show the potential to improve farmers' livelihood and to enhance crop productivity, farmers' actual adoption of these practices is often limited (Vlek, 1990; Franke et al., 2014). One reason for this is that technologies or practices are tested at field or plot level by means of experimentation, whereas the constraints such as labor, equipment and policy arise at the farm or higher levels when farmers manage to replicate these agronomic practices by themselves (Giller et al., 2011).

Analyzing the farming systems within which the rural poor live and work can provide deep insights into strategic priorities for improving the livelihoods of smallholder farmers (Dixon et al., 2001). The main cropping system in Southern Mali is a rotation of cotton-maize-sorghum with most of the purchased inputs applied to the cotton and maize while sorghum benefits from the residual carryover effect from the fertilization (Coulibaly et al., 2014). However, one also has to recognize that there is a wide range of heterogeneities among those farmers within the same farming system (Giller et al., 2011).

So now a "tool" is needed to slice and dice each farming system into "pieces" while still offering a structured framework to identify promising interventions for farmers who share similar resource endowments and are confronted with similar challenges and opportunities. Farm typology is often used as a handy tool for such purposes (Landais, 1998; Tavernier & Tolomeo, 2004; Chikowo et al., 2014;)

> *"A type is an abstract generic model which defines the characteristic features of a series of objects. The term 'typology' designates both (1) the science of type elaboration, designed to help analyze a complex reality and order objects which, although different, are of one kind*

*(farms for instance) and (2) the system of types resulting from this procedure (the farm typology of a given regi*on).” (Landais, 1998)

There is a number of studies exploiting farm typology to analyze smallholder farmers in the context of Africa, yet most of them focused on analyzing the bio-physical aspects of different farm types (Kevane, 1996; Tittonell et al., 2005a; Tittonell et al., 2005b; Tittonell et al., 2010; Dossa et al., 2011; Giller et al., 2011; Sakané et al., 2012). Few studies can be found on analyzing the profitability of smallholder farms by using farm typology (Molua, 2010). A number of studies have been done in developing countries such as India, Kyrgyzstan, Benin, etc. to show the results of profits comparison between organic and conventional cotton (Lakhal et al., 2008; Panneerselvam et al., 2010; Rieple & Singh, 2010; Traore & Bickersteth, 2011; Bachmann, 2012;Kloos & Renaud, 2014). Yet, these studies barely took into account the heterogeneity of farmers when analysing the cotton profits at the regional or country level.

Brock et al. (2002) found that any agro-ecological intensification policy ought to be set in a real livelihood context, to recognize that households with different resources (land, labor and equipment) cope with different constraints and risks. In Southern Mali, four different farm types were classified by CMDT through assessing household equipment ownership like number of weeding tools, plough and oxen (Brock et al., 2002). The aim of this farm typology is to provide an easy-to-implement approach for other agriculture-related institutions to apply suitable technologies and trainings for local farmers (Brock et al., 2002). But the problem is that the CMDT classification scheme is rather limited. Households are classified on the basis of the ownership and mastery of ox-ploughing technology. E.g. if the households have two pairs of oxen and a full set of plough and weeding tools, then they are classified as “fully-equipped” farm type A; If the households have either an ox or a plough, they are classified as “have skills to use tools but not enough for cotton cultivation” farm type C (Brock et al., 2002). Besides, it was introduced for years and now some farmers even possess their own tractors (Duguéa et al., 2008). Thus, it is necessary to provide an updated farm typology that reflects the current farmers’ resource endowments in Southern Mali as a tool to facilitate the extension agents and other farming-related rural institutions to offer technical support for local farmers.

Zorom et al. (2013) made a farm typology based on a survey of 105 households conducted in the community of Tougou in northern Burkina Faso. Four groups of farmers were determined by means of cluster analysis based on household size, age of the household chief, labor availability, number of livestock, number of tools, income source and drought adaptation strategies. The purpose of the typology was to evaluate farmer’s vulnerability to droughts and food insecurity as well as their perceptions of policy incentives (Zorom et al., 2013). This study pointed out that different groupings of farmers have different needs and priorities; therefore, policy interventions should not be a fixed package of solutions but a palette of options that rural farmers could access to depending on their own priorities (Zorom et al., 2013).

1.3 Objectives and research questions

The overall goal is to explore crop intensification options for farmers with different resource endowments. To this end, the following specific objectives were formulated:

- To derive a farm typology based on farm structural characteristics in Bougouni, Southern Mali
- To test the profitability of agro-ecological intensification options for different farm types, mainly focusing on organic cotton production.
- To test the grain and fodder yield increase potential of different intensification options including improved dual-purpose varieties; judicious application of compost in combination with chemical fertilizers; cereal-legume intercropping; seed inoculation.

The research questions associated with these objectives are as follows:

- How does the profitability of organic cotton production in the context of Southern Mali differ between farm types ?
- Can farm typology be used as an entry point for tailoring the agro-ecological intensification options tested in participatory on-farm experiments ?
- How do various intensification options affect the grain and fodder yields compared to the farmers’ traditional practices ?

2. Materials and methods

2.1 Description of the study site

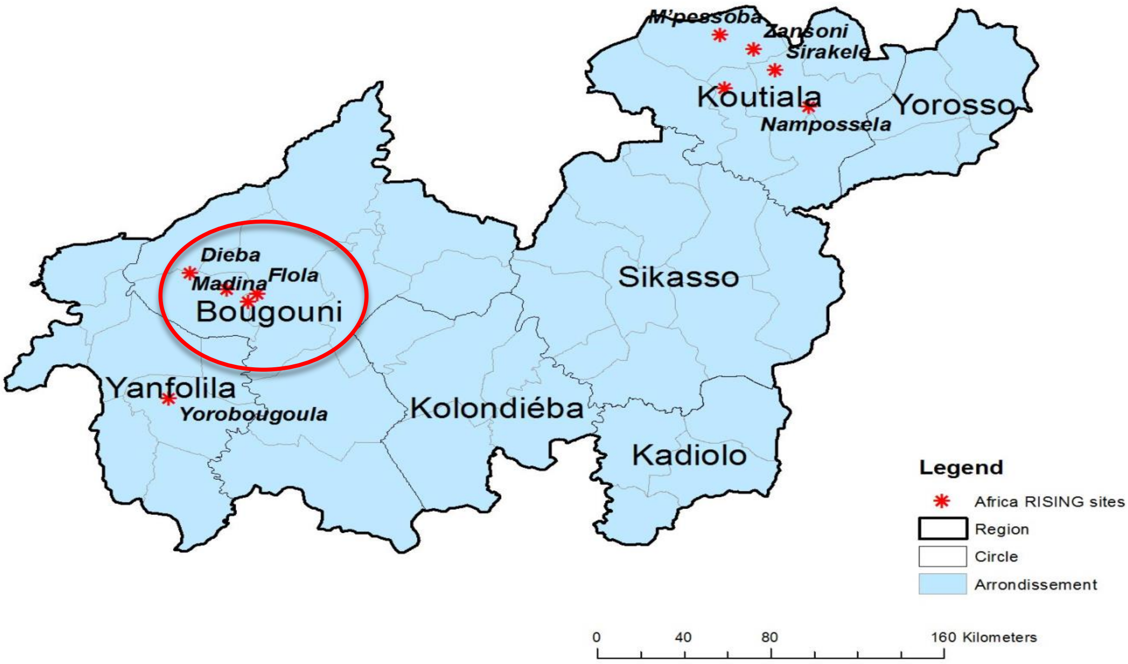

Figure 2. Map of study sites in Bougouni, Southern Mali.
Source: (Timler et al., 2014)

The four study villages are located in the Bougouni region of Southern Mali, which belongs to the Sudanese-Guinean zone with an annual rainfall of 1100 mm, a growing period of 5-6 months starting from June and an annual average temperature of 27°C (Coulibaly, 2006). The soils are predominantly sandy loam with a high gravel content (Timler et al., 2014). Most soils in this region have an organic carbon content of 0.2-1.2%, Olsen P of 3-7 mg/kg and soil pH of 4.5-6 (Timler et al., 2014). Agriculture remains rainfed with highly erratic rainfall during the rainy season (Abdulai & CroleRees, 2001). The main crops are cash crops like cotton, as well as cereal crops (maize, sorghum). Peanut and rice can both be considered as cash and food crops in Bougouni (Timler et al., 2014). Farmers keep cattle and donkeys mainly for draft power and the function of insurance; some farmers also rear small ruminants for sale during festival occasions (Brock et al., 2002; Benjaminsen et al., 2010). Bougouni is one of the typical cotton zones in Southern Mali (Benjaminsen, 2001). Mouvement Biologique Malien (MoBiom), an organic cotton cooperative located in Bougouni, is in charge of the organic cotton inputs dissemination and technical services in the villages. In 2010, there were 73 organic farmer cooperatives with 6,547 certified organic cotton farmers, of whom 30% are women (Nelson & Smith, 2011). Moreover, by using the fair trade premiums from the cotton sales, MoBiom also carried out a number of projects in the local villages. Many of those had already been achieved before 2010, including the construction of 17 storehouses, 3 large water wells, a literacy center, 2 cereal banks, purchase or repair of the primary school desks and benches (Nelson & Smith, 2011)

2.2 Methodology

2.2.1 Farm typology

The typology was derived from household data acquired from CMDT agent in Bougouni and staff of AfricRISING project. The CMDT data consisted of resource endowments variables regarding 204 households of four AfricaRISING villages from Bougouni in 2013. The four villages were Dieba, Madina, Flola and Sibirila. The variables for each household comprised family characteristics (male and female family member, total family workers[2]); livestock (number of cattle, oxen, donkey, ram and goats together); equipment (number of cart, tractor, mill, plough, hoe, weeder, ridger, seeder, multi-cultivator) and land area (the surface area (ha) of cotton, maize, sorghum, millet, rice, cowpea, fonio, peanut, fallow lands). The AfricaRISING data consisted of demographic variables regarding 191 households of the same four villages in Bougouni. The variables comprised the name and ages of the household head and his members, etc.

2.2.2 Survey implementation

The same four villages were chosen to conduct the survey for testing the profitability of organic cotton for smallholder farmers in Bougouni. However, there were no organic cotton producers registered by MoBiom in Madina in 2013, thus only three villages were left for the survey. In order to compare the profitability of the organic and conventional cotton, the information for the conventional cotton was collected from each organic cotton producer.

Firstly, the list of certified organic cotton producers from the Bougouni region in 2013 was collected from MoBiom. The data file contained registration number, producer's name, village, CPCB[3], organic cotton area and cultivation history. From this list, a total of 14 organic cotton farmers from three villages participated in the survey. Several informal semi-structured interviews were held with these farmers in October and November 2014. After the interview, the information of 2009-2013 organic cotton production of 89 producers in each village was also collected from three organic cotton cooperatives (CPCB). The questionnaire paid prime attention to collecting quantitive data for the cotton production of the year 2013, while several qualitative questions were included as well. The data obtained from the survey consisted of cotton land cultivation history for the last three years (2011-2013), household resource endowments (number of workers, cropland area, livestock number, tools number), labor calendars, inputs (seed, organic and chemical fertilizers, bio- and chemical pesticides, herbicides) and output (seed cotton, cereal crops, peanut). Besides, there were formal meetings held with MoBiom staff to grasp a general overview on several economic and practical indicators (organic cotton program operation, input costs, selling prices, etc.). At last, the preliminary survey results were presented to MoBiom staff and further implications and policy interventions were discussed regarding the four villages.

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[2] Family workers represent the male and female of each household who worked on the farm.
[3] CPCB known as Coopératives des Producteurs de Coton Biologique, the local organic cotton cooperative for each village.

2.2.3 Crop trials

A participatory approach was utilized to test various crop intensification options with on-farm trials in four AfricaRISING villages in Bougouni (Figure 2). The tested agronomic packages were discussed with farmers in planning meetings in April and May as well as with MoBiom staff prior to the trials implementation. Farmers could choose different crop trials according to their own preferences. Then, all crop trials were installed on farmers' fields with the supervision of two technicians. Farmers were managing the trials on a regular basis, which included weeding. In each village, there was a contact person who could facilitate and monitor the farmers' field work, thus the key activities could be organized and updated step by step. Technicians and researchers visited the four villages regularly especially during the key crop growth period. After each visit, technicians gave a notice to the farmers who didn't manage the trials timely or properly, e.g., late weeding. The technicians were accompanied by the contact persons who were in charge of seed and other materials dissemination as well as fertilizers application in four villages. Once farmers decided to harvest the trials, they would give a call to the technicians to let them know the harvest process. After harvest, there were several review sessions among researchers, technicians, contact persons and trial participants, in order to get a final feedback from each other and incorporate the key messages into the plan for the trials next year. Through this interactive and connected researcher–technician–contact person–farmer network, the whole process could be monitored. Four types of crop trials were installed in four villages, including maize trials, cowpea trials, soybean trials and sorghum-cowpea intercropping trials. Table 1 provides the details of materials used in each of the crop trial treatments.

2.2.3.1 Soil sampling

Before crop trials demarcation, soil sampling was conducted to assess the soil fertility status of the fields. The soil subsamples were taken at a depth of 0-20 cm using auger. Each soil sample composite was made up of 10 subsamples following W-shaped sampling pattern from each crop trial's plot. These 10 soil subsamples were thoroughly mixed before making each sample composite. Between 500 g to 1 kg was put into a sample bag and then labeled carefully with the name of village, farmer and soil test name. All of the soil samples were sent to the laboratory Sadoré Niger for analysis. The soil tests included: pH (soil to water ratio of 1:2.5), % C (Walkley-black), total N (Kjeldahl digestion), available P (Olsen), exchangeable cations K (flame photometry), cation exchange capacity (CEC) (extraction with ammonium acetate), Ca and Mg (atomic absorption spectrophotometry) and texture (Bouyoucos hydrometer). The results of soil analysis were not obtained in time for inclusion in this thesis.

Table 1. Materials used in the four crop trials. The composition of urea and NPK cereal complex is 46N-0P-0K and 15N-15P-15K respectively. Cowpea variety "Dunanfana" yields no grain but higher fodder, while cowpea variety "Wulibali" yields higher grain but lower fodder comparing to the "Local" variety farmers normally grow.

Crop trials	Treat ment	Design pattern	Variety	Seed (kg/ha)	Neem frequen cy	Seed inoculant	Compost[a] (kg/ha)	Urea (kg/ ha)	NPK complex (kg/ha)
Maize	T1	Sole	Sotubaka	25	n.a.[b]	n.a.	0	0	0
	T2	Sole	Sotubaka	25	n.a.	n.a.	0	75	50
	T3	Sole	Sotubaka	25	n.a.	n.a.	0	150	100
	T4	Sole	Sotubaka	25	n.a.	n.a.	6000	0	0
	T5	Sole	Sotubaka	25	n.a.	n.a.	6000	75	50
	T6	Sole	Sotubaka	25	n.a.	n.a.	6000	150	100
Cowpea	T1	Sole	Local	20	No	n.a.	n.a.	n.a.	n.a.
	T2	Sole	Dunanfana	20	No	n.a.	n.a.	n.a.	n.a.
	T3	Sole	Wulibali	20	No	n.a.	n.a.	n.a.	n.a.
	T4	Sole	Local	20	7[c] days	n.a.	n.a.	n.a.	n.a.
	T5	Sole	Dunanfana	20	7 days	n.a.	n.a.	n.a.	n.a.
	T6	Sole	Wulibali	20	7 days	n.a.	n.a.	n.a.	n.a.
Soybean	T1	Sole	Houla	75	n.a.	Without	0	n.a.	n.a.
	T2	Sole	Houla	75	n.a.	Without	4000	n.a.	n.a.
	T3	Sole	Houla	75	n.a.	With[d]	0	n.a.	n.a.
	T4	Sole	Houla	75	n.a.	With	4000	n.a.	n.a.
Sorghum - cowpea	Ta	Sorghum sole	Local	6	n.a.	n.a.	n.a.	n.a.	n.a.
	Tb	Sorghum sole	Soumalemba	6	n.a.	n.a.	n.a.	n.a.	n.a.
	Tc	Cowpea sole	Local	20	n.a.	n.a.	n.a.	n.a.	n.a.
	Td	Cowpea sole	Dunanfana	20	n.a.	n.a.	n.a.	n.a.	n.a.
	T1	Additive intercrop	Soumalemba + Local C[e]	6+ 20	n.a.	n.a.	n.a.	n.a.	n.a.
	T2	Replacement intercrop	Soumalemba + Local C	6+ 20	n.a.	n.a.	n.a.	n.a.	n.a.
	T3	Additive intercrop	Soumalemba + Dunafana	6+ 20	n.a.	n.a.	n.a.	n.a.	n.a.
	T4	Replacement intercrop	Soumalemba + Dunafana	6+ 20	n.a.	n.a.	n.a.	n.a.	n.a.

Note: [a] Compost represents the composted household waste, crop residue and garbage. [b] n.a. indicates not applicable. [c] Neem was sprayed from floral initiation to pod maturity for the cowpea T4, T5 and T6. [d] Soybean seed was inoculated with rhizobia for the soybean T3 and T4. [e] Local C indicates local cowpea variety.

2.2.3.2 Experiment design

All the trials were laid out in a two-factor experimental design. With respect to the maize trials, the two factors were the applications of compost and chemical fertilizers (urea and NPK complex) respectively (Annex 7). The application rate for the compost included two levels (0; 6000 kg/ha), while the application rate for chemical fertilizers included three levels (0; half recommended dose[4]; full recommended dose). The plant spacing for each treatment was 40 cm intra-row and 75 cm inter-

[4] CMDT recommended 2 bags of NPK complex and 3 bags of urea. Farmers normally apply 1 bag of urea (50kg) and 1 bag of NPK Complex (50kg) to maize and apply little or no fertilizers to rice, sorghum and millet.

row. The two factors for the cowpea trials were composed of variety (Local; Wulibali; Dunanfana) and neem based bio-pesticides application (without neem; with neem) (Annex 8). The plant spacing for each treatment was the same as for the maize trials with 40 by 75cm. In terms of the soybean trials, the two factors were seed inoculation (inoculated; not inoculated) and compost application (0; 4000 kg/ha) (Annex 9), and the plant spacing for each treatment was 10 cm intra-row and 75 cm inter-row. For the sorghum-cowpea intercropping trials, the two factors were cowpea variety (Local; Dunanfana) and cropping pattern (sole cropping; additive intercropping; replacement intercropping) (Annex 10). The plant spacing for the sole cropping plots (Ta, Tb, Tc, Td) was 50 cm intra-row and 75 cm inter-row. For the additive intercropping plots (T1, T3), the planting density for sorghum was the same as Ta, while cowpea density was half of Tc. For the replacement intercropping plots (T2, T4), the sorghum planting density was two thirds of Ta, while the cowpea planting density was one third of Tc.

All crop trials were installed on farmers' fields. The surface area of each treatment plot was 54 m^2 (8 m long and 6.75 m wide). Except for the cowpea trials, all the treatment plots were separated from each other with a strip of 0.75 m width. With regard to the cowpea trials, in order to avoid the pest transfer, the distance between neem treated and non-neem treated plots was 20 m, while plots with the same neem treatment were separated by 0.75 m .

2.2.3.3 Crop management and harvest technique

With regard to maize trials, plowing was combined with seed sowing between mid-June and mid-July, depending on the onset of the rains and farmer's availability. The compost was applied to treatment plots T4, T5 and T6 before plowing. During the first two weeks, NPK complex was applied in combination with first time weeding and replanting. 30 days later, the second mechanical or manual weeding was implemented. Ridging and urea application were implemented after 45 days. Maize was harvested in October by means of excluding margin rows of 1 m width at each side of the plot; the total fresh maize stalks and husked maize cobs were weighed separately with an electronic "Kern" hand balance. Besides, the total number of maize stalks was counted one by one.

The sowing dates for the cowpea trials were between mid-June and mid-July. The calendar for replanting, weeding and ridging of cowpea was the same as the maize trials (15 days, 30 days and 45 days after sowing). Cowpea was harvested from the end of September to the beginning of October by means of excluding margin rows of 1 m width at each side of plot. Fresh cowpea haulms were cut and weighed separately from the cowpea pods directly after harvest, and the number of cowpea haulms was counted one by one from each treatment plot.

Soybean was sown around mid-July. The compost was applied to the soybean treatment T2 and T4 before sowing. The calendar for replanting, weeding of soybean were the same as the maize trials (15 days later, 30 days later). Soybean was harvested from October to November by excluding margin rows of 1 m width at each side of plot; fresh soybean haulms were cut and weighed together with soybean pods directly after harvest. The number of soybean plants from each treatment was counted when harvesting.

For the sorghum-cowpea intercropping trials with replacement intercropping pattern (T2, T4), cowpea and sorghum were sowed at the same day around mid-July. In terms of the additive intercropping pattern (T1, T3), the sowing date for the sorghum was around mid-July, while the cowpea was sown 15 days later. The sowing date for the sole sorghum and sole cowpea was around mid-June. Weeding and replanting were implemented for the intercropping and sole cropping plots 15 days after sowing. 45 days later, mechanical ridging was implemented for all the treatments. The sorghum and cowpea sole plots were harvested from October to November by excluding margin rows of 1 m width at each side of the plot. The replacement intercropping plots (T2, T4) were harvested in October, while the additive intercropping plots (T1, T3) were harvested in November. The total fresh sorghum panicles and stalks as well as cowpea haulms from each treatment were weighed separately. The total number of sorghum and cowpea plants was also counted.

For all the crop trials, a small portion of samples from each treatment plot were put into sample bags, weighed and labeled separately. The labeled samples were oven dried at 80 °C for 48 hours to determine the moisture content and the rest of harvests were left for the farmers.

2.3 Data handling and analyses

2.3.1 Farm typology

The variables that were chosen for making a farm typology comprised eight resource variables, including number of workers, total land (ha), cotton land (ha), herd size (TLU[5]), number of oxen, donkey, total equipment and carts. These variables were closely related to farmers' key practices and activities. Before running the analysis, the data was pre-examined by matching the household survey data from AfricaRISING project to the household survey data from CMDT. If the name of the household head in the CMDT data file didn't appear on the list of AfricaRISING data file, then the untraceable names were eliminated from the CMDT database. As such, 40 households were left out, and 164 households were retained.

Two potential outliers with herd size bigger than 70 TLU were excluded after examining the boxplot of each variable with R (R Core Team, 2014). Pearson's correlation among these variables were examined with "pairs ()" function, and if two variables either have correlations more than 90% or less than 50%, they were removed. Thus, one variable (donkey) was removed, and a final dataset of 162 households and seven resource variables was obtained. The seven variables were: Number of workers, total land (ha), cotton land (ha), herd size (TLU), number of oxen, total equipment and carts. A principal component analysis (PCA) was first run with R (Dray & Dufour, 2007), followed by a hierarchical cluster analysis (HCA) in R (R Core Team, 2014). The "Ward's - agglomeration method" was used to cluster the obtained principal components. The clusters were investigated by means of a histogram and dendrogram before breaking into different groups, and the appropriate number of groups was determined by examining the vertical distance (also called "jump") between the clusters branches (Kabacoff, 2014). For each farm type, extra variables were also calculated to describe the farm type characteristics. These included worker/land ratio, TLU/land ratio, oxen/land ratio and tools/land ratio.

[5] TLU means Tropical Livestock Units, 1 TLU = 250 kg of live weight of ruminants. Male draft oxen=1 TLU, male and female cattle (bovine) =0.7 TLU, donkey=0.5 TLU, ram/goat=0.2 TLU (R. Wilson, 1986).

2.3.2 Cotton production

In Dieba and Sibirila, the data of organic cotton production included information on both output (kg) and land area (ha). However, no data on land area was available for Flola, thus the five years average yield (2009-2013) for Flola only contained information from four respondents who participated in the interview, since the information on cotton land area and output could be recorded. Apart from the 14 organic cotton producers who took part in the interview, there were another 12 organic cotton producers, whose production was recorded by the organic cotton cooperatives and could be traced back to the CMDT dataset, allowing classification in one of the farm types. In total, there were 26 organic cotton producers who both had yield data in 2009-2013 and could be classified into one of the farm types. Descriptive statistics were performed for analyzing the data of the cotton production.

Most organic cotton respondents reported that they applied compost, while two respondents mentioned that they corralled cattle in the organic cotton fields. Since the local cart has a standard size, both MoBiom staff and farmers normally use cartload as a basic unit for the amount of applied compost. One cart was estimated to contain 100 kg of compost (M. Ollenburger, personal communication, October, 2014). In case of the corralled cattle, it was assumed that one TLU produced about 1600 kg fresh manure per year with a dry matter content of 60% (Defoer et al., 2000).

2.3.3 Cotton gross margin analysis

The profitability comparison between the organic and conventional cotton was based on a gross margin analysis. Gross margin analysis could give a useful indication of the economic efficiency of a farm (Firth, 2002). Aggregated cotton inputs, outputs and profits for each farm type was calculated.

Gross margin (GM) was computed as the revenue (Re) minus the total variable costs (TVC). Revenue was calculated as cotton yields multiplied by the seed cotton price. Total variable costs include the cost of inputs (Ci) (seeds, fertilizers, pesticides, herbicides), the costs of hired labor (Chl) and the cost of annual maintenances (Cam). The cost of annual maintenances was calculated as the yearly cost of medicine shots (Cm) for the oxen and donkey plus the yearly cost of equipment repair (Cer), divided by total crop areas (Tca), and then multiplied by the area of a specific crop ($A_{(c)}$). Farmers normally feed the crop residues to the animals, so that the cost of feed was assumed to be zero. Except for the sprayer, the production tools and draft animals that were used for the organic cotton were the same as for the conventional cotton. Therefore, the annual maintenances cost was similar for the organic and conventional cotton on a per-hectare basis. No cost of annual maintenance was assigned to the sprayer because farmers didn't repair it. For the organic cotton, the cost of compost was assumed to be zero, because farmers neither purchase nor sell compost. However, the cost of hired and family labor for applying compost was recorded, and the cost of applying compost by family labor was reflected on the net income per family worker.

$$GM = Re - TVC$$

$$TVC = Ci + Chl + Cam$$

$$Cam = \frac{(Cm + Cer)}{Tca} \times A(c)$$

The net income (NI) was calculated as gross margin (GM) minus the cost of amortization (CA). Amortization cost was calculated by using the straight line depreciation method (Davey, 1979).

Amortization cost was calculated as total fixed costs (Tfc) minus the salvage value (Sv), divided by life expectancy (Le) and total crop areas, and then multiplied by the area of a specific crop. Total fixed costs were the cost of draft animals (donkey, oxen), and equipment (cart, weeder, ridger, multi-cultivator, plough and sprayer). Organic cotton had higher equipment amortization costs than conventional cotton since the same sprayer was used for both conventional cotton and maize, while a separate sprayer was required for growing organic cotton. The salvage value for both draft animals and equipment was assumed to be zero when calculating the amortization costs. Indeed, farmers exploited the donkey and oxen until they were too old or too sick to work. If the animals died, they were disposed of. Apart from the sprayers, other tools could be used for a long time as long as farmers kept replacing the broken parts. Sprayer was used until it didn't work and then being disposed of. Table 2 provides an average fixed costs for the equipment and animals.

$$NI = GM - CA(j)$$
$$CA(j) = \frac{(Tfc - Sv)}{Le \times Tca} \times A(c)$$

Table 2. Fixed costs, salvage value, life expectancy and the cost of annual maintenances for the draft animals and equipment.

	Donkey	Oxen	Cart	Ridger	Weeder	Multi-cultivator	Plough	Sprayer
Fixed cost (Fcfa[6])	50000	180000	150000	30000	25000	35000	25000	12500
Salvage value (Fcfa)	0	0	0	0	0	0	0	0
Life expectancy (year)	4	8	20	30	30	30	30	2
Annual maintenance costs (Fcfa)	5000	5000	7500	600	600	600	600	0

2.3.4 Profits analyses at the household level

The respondents did not only grow cotton, but also maize, rice, sorghum, millet and peanut. The selling price for the crops was based on the average price of the year 2013 in Bougouni (Timler et al., 2014). The costs of artificial fertilizers and chemicals for the cereal crops were estimated based on the recommended application rates by CMDT[7]. Table 3 provides the cost of materials for different crops. The cost of fertilizers was attributed to maize only, and for the farmers who yielded above 2000 kg/ha, we assumed that the full dose of recommended fertilizers was applied. For those with maize yields below 2000 kg/ha, it was assumed that only half the recommended dose was applied. A break point of 2000 kg/ha was determined based on the average maize yields in Bougouni (Laris & Foltz, 2014). Based on farmers' common fertilizer application rates, it was assumed that food crops other than maize did not receive any fertilizer (M. Ollenburger, personal communication, October, 2014). It was rather common among the farmers to use the seed saved from previous year for the crops other than cotton, thus no cost for seed was included. Besides, no cost for hiring labor was included because it was assumed that family workers did the majority of field works for the food

[6] Fcfa (CFA franc), is the currency used in eight West Africa countries. 1 Euro = 655.957 Fcfa.
[7] The officials provide subsidized cotton NPK complex and cereal NPK complex, and the price of the two was similar. Cotton NPK complex (14N-22P-12K-7S-1B) and cereal NPK complex (15N-15P-15K). *Source: (Fuentes et al., 2011)*

crops. In order to calculate the household net income consistently across all crops, the costs of hired labor for both organic and conventional cotton were excluded as well.

Scenario 1:
It was assumed that 100% of the crop production was sold on the market directly. The household profits were calculated as crop production (Cp) multiplied by selling price (Sp) subtracted by the variable costs (VC) (cost of chemicals, fertilizers) and amortization costs (CA)

$$Profits = Cp \times Sp - VC - CA$$

Scenario 2:
It was assumed that the food crops were first used to meet the food requirements of the household and the crop surplus was sold on the market. The consumption ratio of the food crops was determined based on the indicators (1) household energy requirements; (2) crop consumption and sale pattern in the Bougouni region.

(1) The household daily energy requirement was calculated as the number of adult male equivalents[8] multiplied by the daily energy requirement for an adult male at the age of 30-60 of 2900 kcal (Smith & Subandoro, 2007). Since farmers consumed meat or dairy products only on festival occasions, it was assumed that the food crops served as a prime energy source. The energy content of maize, rice, millet, sorghum and peanut was 3650, 3600, 3780, 3390, 5670 kcal/kg respectively (Han & Foltz, 2013; Masters et al., 2013).

(2) Timler et al. (2014) reported that the sales of cereal crops averaged 15-20% of the production while the sales of peanut and rice was about 50% of the production in Bougouni. Based on this information, indicative proportions for the consumption of maize, sorghum, millet, peanut and rice were assumed at 90%, 90%, 70%, 50% and 50% of the total production respectively. The consumption ratio of the cereals and peanut were assumed to be lower than the indicative proportions when a household's energy requirements were far lower than the total food energy supply.

A household was considered as food energy deficient when its food energy requirements went above the food energy supply at the indicative proportions. It was assumed that this household would fill the calorie gap by purchasing maize grain on the market because of its availability throughout the season and its relatively low price (Diallo, 2011; Timler et al., 2014). Besides, 15% storage losses were taken into account for the calculation (Sundberg, 1988).

Thus, the household profits were calculated as crop production (Cp) subtracted by household consumption (Hc) and storage loss (Sl), and multiplied by selling price (Sp), then subtracted by variable costs (VC) and amortization costs (CA). In case of food energy deficient, the purchase cost was also included by using the household energy deficiency value (Hed) divided by energy content of maize, and then multiplied by the market price of maize (Pm).

$$Profits = (Cp - Hc - Sl) \times Sp - VC - CA$$

$$Purchase = \frac{Hed}{3650} \times Pm$$

[8] Adult male equivalents = number of household members×0.79 + 0.0038, the number of household members indicates the number of female and male in the household, derived from M. Ollenburger based on (Smith & Subandoro, 2007). The adult male equivalents was only used for calculating household food consumption in this paper.

Table 3. Material costs at the recommended input rate for different crops (actual application rates are lower). Org_cotton indicates organic cotton, and Con_cotton indicates conventional cotton.

	Org_cotton	Con_cotton	Maize	Peanut	Rice	Sorghum	Millet
Seed (Fcfa/ha)	1075	1500	8000	19500	12000	2400	1600
Fertilizer (Fcfa/ha)							
Urea	n.a.	15000	15000	0	45000	15000	15000
NPK Complex	n.a.	45000	15000	0	30000	30000	30000
Compost	0	0	0	0	0	0	0
Pesticides (Fcfa/ha)							
Nomax 150 SC	n.a.	4500	0	0	0	0	0
Tenor 500 SC	n.a.	4585	0	4585	0	0	0
Fanga 500 EC	n.a.	4535	0	4535	0	0	0
Neem seeds	600	0	0	0	0	0	0
Koby oil	300	0	0	0	0	0	0
Herbicides (Fcfa/ha)							
Glycel 41% SL	n.a.	3500	3500	0	0	0	0
Super Glue	n.a.	4000	0	0	0	0	0
Kalach 120 SL	n.a.	0	4000	0	0	0	0
Total (Fcfa/ha)	1975	82620	90500	28620	87000	47400	46600

Source: (Gueguen, 2010; Beaman et al., 2013; Coulibaly et al., 2014; Timler et al., 2014)

2.3.4 *Crop trials analyses*

The statistical tests on the dry matter yields were conducted in R (R Core Team, 2014). The normality and homogeneity of variance was examined by Shapiro-Wilk test and Levene's test respectively. A Kruskal-Wallis one-way analysis of variance was tested before conducting the multiple comparisons within the groups. For sorghum-cowpea trials, intercrop productivity was analyzed based on the land equivalent ratio (LER) (Rao & Willey, 1980). A LER value greater than 1 indicates that intercropping has a land use advantage over sole cropping, and vice versa (Willey, 1979). The partial land equivalent ratio of sorghum (pLERs) was calculated as the intercrop sorghum grain yield ($Y_{in,s}$) divided by sole sorghum grain yield ($Y_{sole,s}$). The partial land equivalent ratio of cowpea (pLERc) was calculated as intercrop cowpea haulm yield ($Y_{int,c}$) divided by sole cowpea haulm yield ($Y_{sole,c}$). The total land equivalent ratio of both crops (Total LER) was computed as the sum of the two partial LER.

$$Total\ LER = pLERs + pLERc = \frac{Yint, s}{Ysole, s} + \frac{Yint, c}{Ysole, c}$$

Descriptive statistics were used for analyzing the profitability of each treatment for the crop trials. The air-dried harvests were used for calculating the sold amounts among all the crop trials.

3. Results

3.1 Farm typology

In the process of PCA, two principal components were obtained to explain the largest variance (83%) with the first principal component explaining 71% of the total variance and the second principal component explaining 12% of the total variance (Figure 3). Two groups of variables could be identified, including the first group of assets related variables (tlu, cart, oxen, equip) and second group of resources related variables (cotton, totland, worker). The majority of households were densely encircled around the cross of the two principal components accompanied with few households dispersed at the further left side of the first principal component (PC1).

Five clusters were determined based on these two principal components (Annex 3), thus the total 162 households were classified into five different farm types. The five clusters were plotted by two main principal components as shown in Figure 4. It was worth noting that farm type 1, 3 and 5 had higher values regarding resources related variables while farm type 2 and 4 had higher values in terms of the assets related variables.

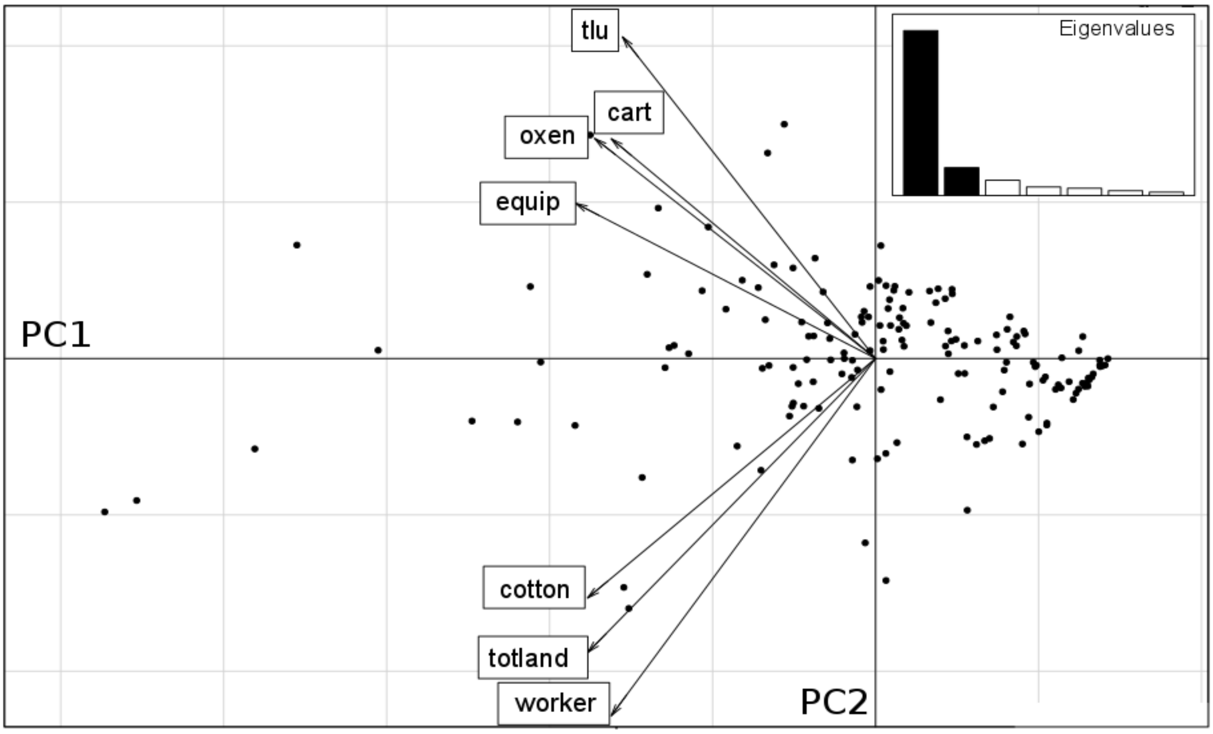


Figure 3. A scatter diagram of variables and households (black dots) in the two-dimensional space of two principal components. The two black bars at the top right corner of the figure indicate the eigenvalues of two principal components by 4.97 and 0.84 respectively.

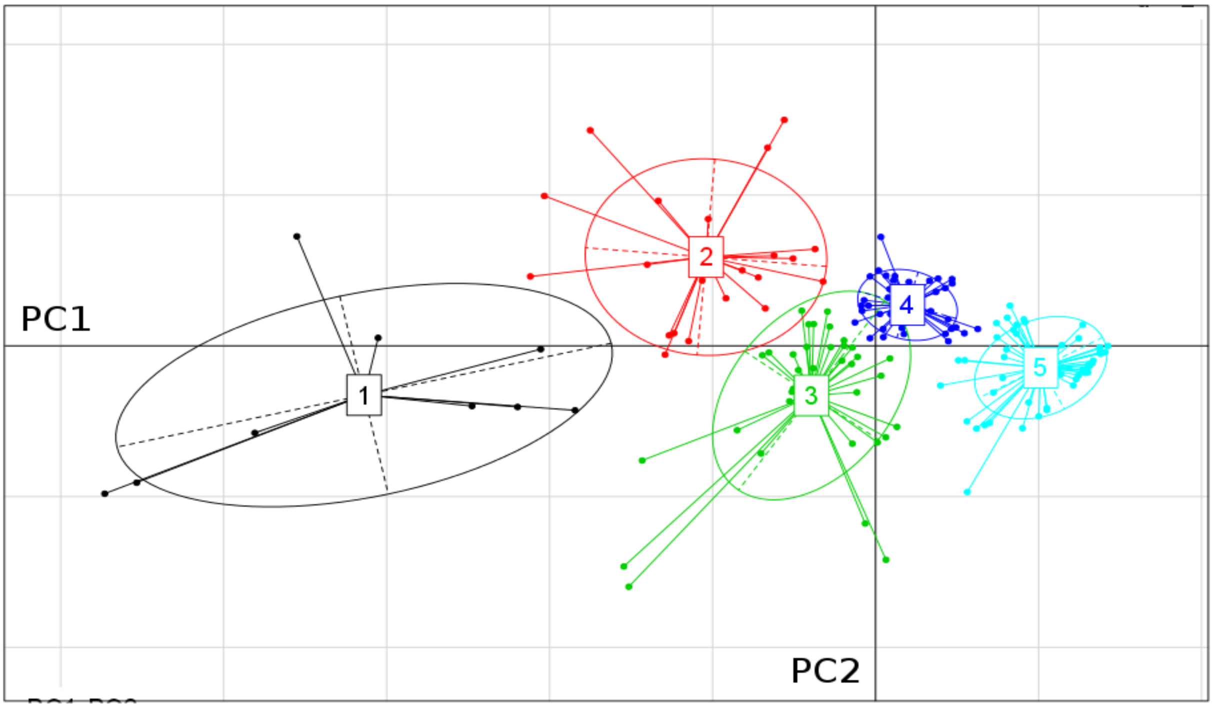


Figure 4. A scatter diagram of five groups by two principal components.

The farm type classification tree was created based on the typology results dataset (Figure 5). Resources variables included number of workers, total land area, cotton area, herd size (TLU) and number of carts were harnessed, allowing households being classified into one of the farm types.

Among the total 162 households, 6%, 13%, 23%, 25% and 34% were classified as farm type 1, 2, 3, 4 and 5 respectively. In Dieba and Sibirila, farm type 5 made up the biggest proportion of the total households with 38% and 33% respectively. The majority of the total households in Flola falls into farm type 3 by 32% whereas in the village of Madina, farm type 4 and 5 contributed nearly equal proportions of 36% and 34% respectively.

Table 4 provides a detailed characterization for five farm types. Farm type 1 had three times more family workers than farm type 2 and 3 and five times more family workers than farm type 4 and 5. Regarding the total land size, farm type 1 was twice as big as farm type 2 and 3 and four times as big as farm type 4 and 5. Except for type 5 farmers, farmers of all the farm types distributed about 1/3 of the total land area to growing cotton. The herd size of farm type 1 was six times larger than that of farm type 3 and 4 and twenty-two times larger than that of farm type 5. Farm type 1 owned more tools than other farm types, by contrast, farm type 5 only possessed one tool. With regard to the ratio variables, farm type 1, 3 and 4 had a higher worker/land ratio, while farm type 2 and 4 had a higher oxen/land and tools/land ratio.

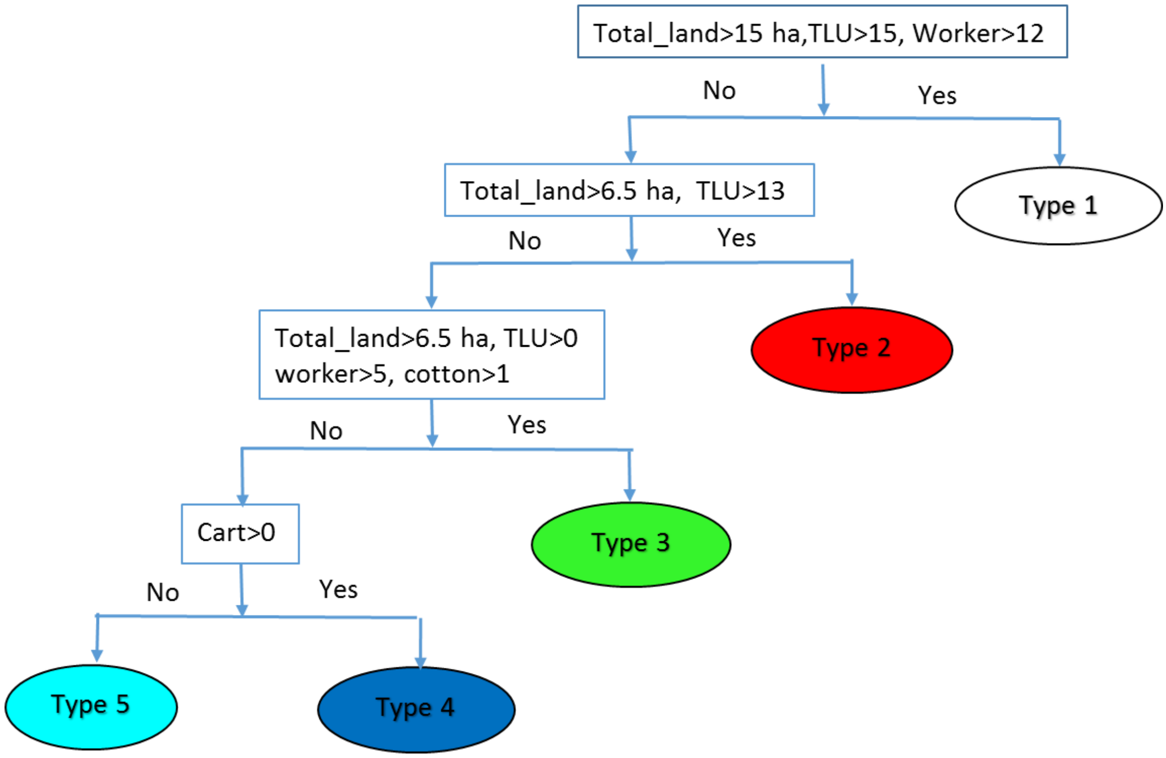


Figure 5. Farm type classification tree for four villages in Bougouni.

Table 4. Characterizations of average variable value by farm type in Bougouni. N=9, 21, 37, 40, 56 households for each farm type respectively. SD indicates standard deviation.

	Farm type				
	1	2	3	4	5
Worker	22	7	9	4	4
SD	*7.34*	*3.68*	*4.52*	*1.95*	*1.68*
Total Land (ha)	24.3	10.8	11.8	5.4	4.1
SD	*7.12*	*3.84*	*4.19*	*1.25*	*2.89*
Cotton land (ha)	7.3	3.2	3.3	1.5	0.7
SD	*3.14*	*1.26*	*1.16*	*0.68*	*0.73*
Herd Size (TLU)	32.8	26.7	5.5	5.4	1.5
SD	*10.73*	*12.64*	*3.04*	*3.37*	*2.11*
Oxen (head)	6	4	2	2	1
SD	*1.32*	*1.32*	*0.85*	*0.55*	*0.83*
Tool (set)	8	5	3	3	1
SD	*2.11*	*1.39*	*1.29*	*0.85*	*0.85*
Cart (set)	2	1	1	1	0
SD	*0.87*	*0.30*	*0.35*	*0.27*	*0.19*
Worker/land ratio	0.9	0.7	0.9	0.7	1.1
SD	*0.33*	*0.34*	*0.56*	*0.38*	*1.16*
TLU/land ratio	1.4	3.2	0.5	1.0	0.4
SD	*0.43*	*3.36*	*0.37*	*0.65*	*0.52*
Oxen/land ratio	0.3	0.4	0.2	0.4	0.2
SD	*0.09*	*0.12*	*0.13*	*0.14*	*0.26*
Tools/land ratio	0.3	0.5	0.3	0.6	0.2
SD	*0.07*	*0.29*	*0.14*	*0.18*	*0.26*

3.2 Cotton production and profits analyses

3.2.1 Cotton supply chain and externalities

CMDT holds an exclusive control over the entire conventional cotton supply chain (input supply and sales of cotton lint) and a partial control over the organic cotton supply chain (sales of cotton lint) (Nelson & Smith, 2011). There were cotton farmer organizations in each village, known as CPC (Coopératives de Producteurs de Coton) organized by CMDT to manage input supply and cotton harvest (Nelson & Smith, 2011). Cotton seed, chemical fertilizers (urea and NPK complex), herbicides, pesticides, sprayers and other equipment could be ordered in advance through the CPC according to the cotton land size. In addition, MoBiom also facilitated the establishment of local village cooperatives, known as CPCB (M. Ollenburger, personal communication, October, 2014). CPCB provided bio-pesticides, sprayers and other materials for organic cotton farmers. After harvest, both conventional and organic seed cotton were collected by CMDT and then transported to the nearest ginner plants (Lakhal et al., 2008). After ginning, the conventional cotton was baled and sold on the international markets (Lakhal et al., 2008). The organic cotton bales were labeled as organic before being sent to India to be manufactured (Lakhal et al., 2008). After that, the organic cotton garments were sold on the European markets (Lakhal et al., 2008). Once CMDT got payments from the buyers, the total sales of conventional cotton were paid back to the farmers after deducting the cost of ordered products from each farmer (MoBiom, formal meeting, August 20, 2014). The conventional seed cotton price paid to farmers in 2013 was 250 Fcfa/kg. With respect to organic cotton, the cash flow was more complicated. At first, CMDT deducted the cost from the organic cotton producers who ordered materials or equipment from CMDT, and then the total sales of organic cotton went to MoBiom. Secondly, MoBiom deducted the cost from the producers who ordered materials or other equipment. Besides, a 10 Fcfa/kg tax extracted from the fairtrade premium (34 Fcfa/kg) and a cotton sales tax (28 Fcfa/kg) were kept with MoBiom as operation costs and investment funds for the rural development. Thirdly, the remaining faitrade premiums of 24 Fcfa/kg were paid to local CPCB for administrative costs. Lastly, 300 Fcfa/kg was paid to the organic cotton farmers by CPCB.

Helvetas Mali founded MoBiom in 2002 (Nelson & Smith, 2011). In the past, MoBiom and Helvetas Mali jointly paid the cost of organic certification (MoBiom, formal meeting, August 20, 2014). At the moment, the entire organic certification cost is paid by Helvetas Mali due to internal problems of MoBiom (MoBiom, formal meeting, August 20, 2014). MoBiom also offers training sessions for the organic cotton farmers about topics related to the reasonable dosage of bio-pesticides and organic fertilizers, how to better harvest and store cotton, and how to comply with the organic standards (MoBiom, formal meeting, August 20, 2014). Besides, there are some incentives for the organic cotton farmers provided by MoBiom. One example is the "half-price-cart" (A. Samaké, farmer interview, November 4, 2014). Basically, if one organic cotton farmer gets high yields in three consecutive year, then he can purchase the cart from the market or MoBiom for half the price with the other half being paid by MoBiom.

3.2.2 Organic cotton production in Bougouni

In 2013, there were a total of 81 organic cotton producers from 7 village cooperatives (CPCB) in the Bougouni region registered by MoBiom, and the surface area per farm for the organic cotton varied from 0.25 ha to 1 ha.

The number of organic cotton farmers in three villages in 2009-2013 was shown in Figure 6. In Sibirila, the number of organic cotton participants declined sharply from 38 in 2009 to 5 in 2013. In Dieba, the number of participants fluctuated until 2011 before dropping abruptly to 5 in 2013. In Flola, the number of participants dropped from 15 in 2011 to 4 in 2012 and then leveled off in 2013.

According to respondents' complaints during the interview as well as the derived information for the organic cotton yields for the last five years, several reasons for the high dropout rates were summarized as follows:

- Late payment
  Whereas the organic cotton was harvested between October and November, the payment would normally arrive at CPCB when next season's crops had been planted (July).
- High labor demand
  There was a high labor demand for the organic cotton because synthetic chemicals and fertilizers were not allowed to be used. E.g., one person could apply chemical fertilizers in less than a day, while the application of 40-60 carts of compost could last for several weeks.
- Breach of promise by MoBiom
  In Flola, the farmers reported that MoBiom promised the farmers to purchase the cotton at a price of 300 Fcfa/kg, but eventually the farmers were paid only 250 Fcfa/kg, which was the same price as the conventional cotton.
- Lack of joint participants
  In Flola, one respondent mentioned that he was the only one who grew organic cotton in the village before 2011, and he had to join another village cooperative that was a bit far from Flola for ordering materials like neem or transporting the harvested seed cotton.
- Low yield
  Organic cotton yield declined year by year in Dieba and Flola, while the yield in Sibirila remained low for the last four years (Table 5), which could be another reason for such a high dropout of organic cotton farmers.

The average yields of farm type 4 was relatively higher than that of farm type 1, 2, 3 and 5 (Figure 7). For farm type 1, the yields ranged from 196 to 806 kg/ha with an average yield of 442 kg/ha. The yields of farm type 2 ranged from 213 to 522 kg/ha with an average yield of 384 kg/ha. The yields of farm type 3 varied from 12 to 684 kg/ha with an average yield of 352 kg/ha. For farm type 4, the yields ranged from 97 to 943 kg/ha with an average yield of 472 kg/ha. For farm type 5, the yields varied from 82 to 540 kg/ha with an average yield of 240 kg/ha.

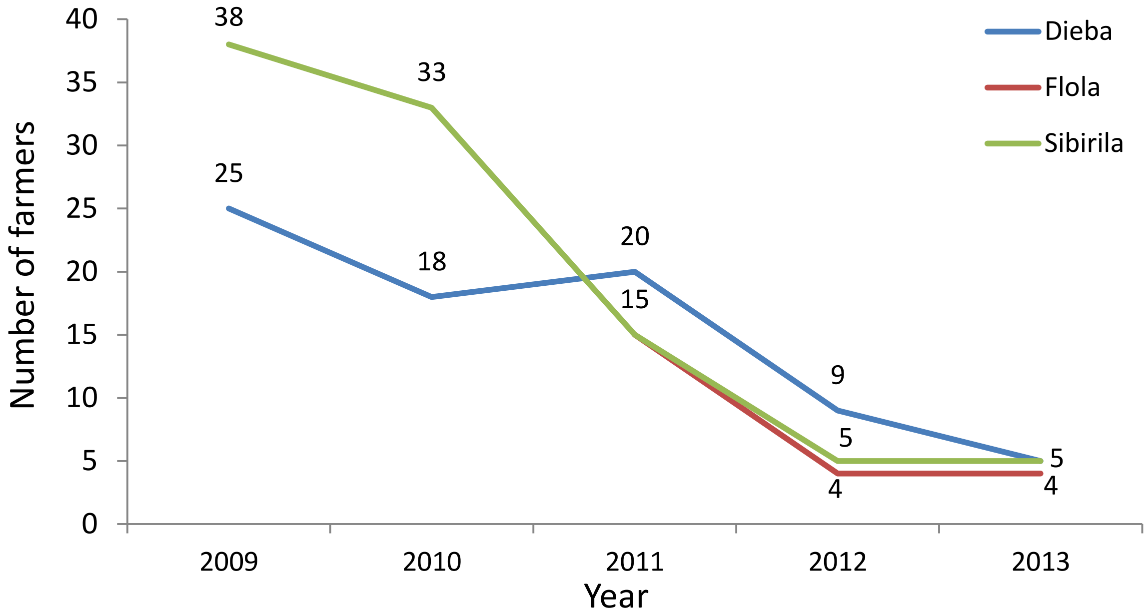


Figure 6. Number of organic cotton producer in three villages from 2009 to 2013.

Table 5. Average organic cotton yield (non-italic value) and standard deviation (*italic value*) in three villages from 2009 to 2013. N=36, 4, 48 households from Dieba, Flola and Sibirila respectively.

	Yield (kg/ha)				
	2009	2010	2011	2012	2013
Dieba	563	484	445	172	215
	475.3	*250.1*	*324.9*	*173.6*	*176.0*
Flola	n.a.	n.a.	517	552	459
	n.a.	*n.a.*	*310.0*	*n.a.*	*279.0*
Sibirila	367	346	319	378	626
	314.4	*301.6*	*327.9*	*352.8*	*267.4*

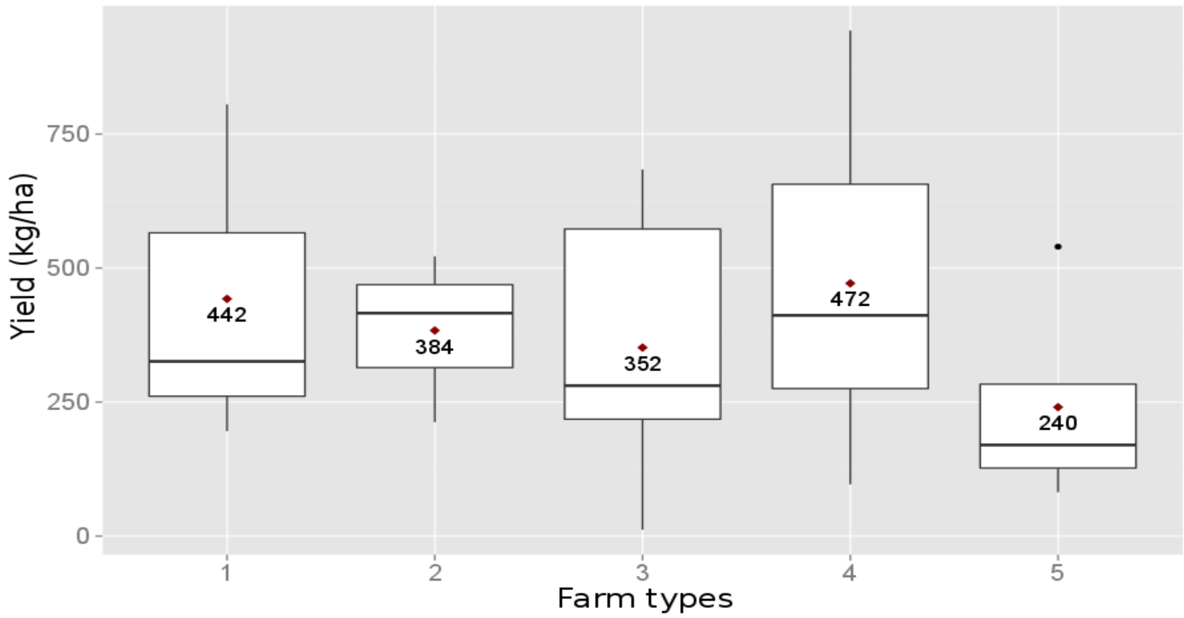


Figure 7. Five years' organic cotton yield (kg/ha) for five farm types (2009-2013), red dot with value indicates average yield, and middle line indicates median yield. N= 3, 3, 8, 8, 4 farmers for each farm type respectively.

3.2.3 *Cotton inputs comparison and profits analyses*

The fertilizer application rate for the conventional cotton was similar among five farm types while the fertilizers input for the organic cotton was rather low for farm type 2 and 5. No big difference was observed on the neem use among the five farm types, while the pesticides dose for the conventional cotton varied widely within and between the five farm types (Table 6).

Among the fourteen farmers who participated in the survey, eleven farmers grew both organic and conventional cotton, three farmers only grew organic cotton in 2013. For farm type 3, in particular, four farmers grew both organic and conventional cotton but two farmers only grew organic cotton. In order to aggregating data for each farm type in a consistent way, these two farmers were left out in the cotton profits analyses and household profits analyses.

The land size of conventional cotton was at least three times bigger than that of organic cotton among all farm types. For farm type 3, the land size of organic cotton was nearly twelve times smaller than that of conventional one. Moreover, the yield of conventional cotton was two times higher than that of organic cotton, and especially for farm type 3, the yield of conventional cotton was nearly four times higher than that of organic cotton. However, the selling price for organic seed cotton was 50 Fcfa/kg higher than that of conventional seed cotton in 2013. The revenue of the organic cotton was nearly two times lower than that of the conventional cotton for each farm type.

The variable costs of the organic cotton were four times less than that of the conventional cotton among all farm types. Farm type 3 in particular, the variable costs of the organic cotton was nearly twenty times less than that of the conventional cotton. In contrast, the amortization cost of the organic cotton was two times higher than that of conventional cotton for farm type 1, 2 and 3. It was worth noting that farm type 4 had the highest hired labor costs regarding organic cotton whereas there was no hired labor costs for farm type 3 and 5. Overall, the total costs of the conventional cotton were two times higher than that of the organic cotton among the five farm types.

Conventional cotton was more economically viable than the organic cotton with higher gross margin and net income for farm types 1 to 4 with farm type 1 achieved the highest net income and farm type 4 got the highest net income per family worker. Farm type 4 and 5 were capable of reaping higher net income for the organic cotton per family worker per hectare than the other farm types.

Table 6. A comparison of cotton inputs and yields in 2013 for all cotton farmers interviewed (N=14).

Farm types	Organic (kg/ha)				Conventional (unit/ha)				
	Manure	Compost	Neem	Yield	Herbicide (L)	Pesticide (L)	Urea (kg)	NPK Complex(kg)	Yield (kg)
1	0	2000	4	174	2	1.2	50	150	1250
1	400	1600	4	756	2	0.4	50	150	2382
2	480	0	4	92	1	1.2	50	150	800
2	0	0	5	492	1	5	50	150	667
3	4200	0	3	476	2.3	2.4	50	150	1011
3	0	0	6	430	1	1	50	150	1326
3	0	4000	4	796	1	4	50	150	867
3	0	2000	4	116	1	5	50	150	1115
3	0	4000	10	556	n.a.	n.a.	n.a.	n.a.	n.a.
4	0	2000	1	282	n.a.	n.a.	n.a.	n.a.	n.a.

4	4000	8000	4	298	2	2.4	50	150	1000
4	0	0	4	36	4	2.4	50	150	1300
4	0	4000	5	998	1	0.2	50	150	1200
5	0	0	4	540	n.a.	n.a.	n.a.	n.a.	n.a.

Table 7. Average gross margin of organic and conventional cotton for five farm types in Bougouni in 2013. N=2, 2, 4, 3, 1 respondents for each farm type respectively. For farm type 5, the respondent didn't grow conventional cotton.

	Organic					**Conventional**			
Farm Type	1	2	3	4	5	1	2	3	4
Area (ha)	0.38	0.38	0.31	0.58	0.25	1.25	3.0	3.6	1.8
SD	*(0.18)*	*(0.18)*	*(0.13)*	*(0.38)*	*(n.a.)*	*(1.06)*	*(0)*	*(0.95)*	*(0.76)*
Yield (kg/ha)	465	292	455	444	540	1816	733	1080	1000
SD	*(411.5)*	*(282.8)*	*(278.3)*	*(193.4)*	*(n.a.)*	*(800.4)*	*(94.3)*	*(193.4)*	*(435.9)*
Price(Fcfa/kg)	300	300	300	300	300	250	250	250	250
Revenue (Fcfa/ha)	139500	87600	136350	133200	162000	454000	183333	269968	250000
Variable cost (Fcfa/ha)									
Seed	1075	1075	1075	1075	1075	1500	1646	1180	1600
Hired labor	8000	9000	0	17333	0	2500	3500	9939	17333
Fertilizer	0	0	0	0	0	75000	37500	60000	48000
Chemicals	3550	1900	1938	2133	3300	16278	20205	21230	21315
Maintenance	774	2386	1801	3395	1111	774	2386	1801	3395
Total	13399	14361	4813	23937	5486	96051	65237	94150	91643
Amortization (Fcfa/ha)									
Draft animal	3608	4956	3698	10094	0	3608	4956	3698	10094
Equipment	19965	15994	12783	9105	0	5121	3286	2647	8184
Total	23573	20951	16480	19199	0	8730	8242	6345	18278
Total cost (Fcfa/ha)	36972	35312	21294	43136	5486	104781	73479	100495	109921
Gross margin (Fcfa/ha)	126101	73239	131537	109263	156514	357949	118097	175818	158357
Net income (Fcfa/ha)	102528	52288	115056	90064	156514	349219	109854	169473	140079
Farm worker (Fcfa)									
Per worker	6835	5229	12839	43580	78257	23281	10985	19424	61521
Per day	582	1868	2081	1578	2302	5044	2877	9059	3345

3.2.4 The sales of crops at the household level

All the respondents grew maize and peanut, thirteen respondents grew rice, eight respondents grew sorghum and two respondents grew millet in 2013. The household profits for all the crops was calculated based on two scenarios, i.e., scenario 1 : all of the crop productions were sold on the market; scenario 2 : crop sales excluding the amount of household consumption. In scenario 2, three households produced fewer calories than they acquired, including one households for farm type 2 (-2,907,399 kcal) and two households for farm type 3 (-2,520,812 kcal, -2,867,077 kcal) (Table 8). Farm type 1 had the highest sold amounts of crops in scenario 1 and 2 while farm type 5 sold the least amount of crops on the market in both scenarios (Table 9).

Table 8. household food energy needs (kcal), crops energy supply (kcal) and the amount of energy surplus/deficit (kcal) at the household level in scenario 1 (Sce 1) and scenario 2 (Sce 2) in 2013. N=2,2,4,3, 1 respondents for each farm type respectively.

Farm type	Household needs	Crop supply		Energy surplus/deficit	
		Sce 1	Sce 2	Sce 1	Sce 2
1	42232880	75751000	42417720	33518120	184840
2	13801570	29889375	12350787	16087805	-1450783
3	17146430	26670350	15821051	9523920	-1325379
4	5300051	23992800	5385879	18692749	85828
5	3348882	5833500	3349323	2484618	441

Table 9. Average sold amounts of five crops (kg) by five farm types in scenario 1(Sce 1) and scenario 2 (Sce 2) in 2013. N=2, 2, 4, 3, 1 respondents for each farm type respectively.

Farm type	Maize		Peanut		Rice		Sorghum		Millet	
	Sce 1	Sce 2	Sce 1	Sce 2	Sce 1	Sce 2	Sce 1	Sce 2	Sce 1	Sce 2
1	12500	1700	3300	2168	1125	886	1000	85	3000	255
2	4800	904	1200	765	1440	771	225	0	n.a.	n.a.
3	3775	106	1193	393	1175	627	450	28	800	0
4	2800	975	1890	1417	833	708	50	4	n.a.	n.a.
5	900	0	300	0	250	0	n.a.	n.a.	n.a.	n.a.

Due to the high cost of fertilizers and chemicals, some farmers reaped deficit net income in scenario 2. The deficit net income was shown in the household profits (Figure 8). Farm type 1 got the highest net income by 3,196,400 Fcfa in scenario 1 and 1,225,000 Fcfa in scenario 2, followed by farm type 3, 4 and 2. By contrast, farm type 5 earned the lowest net income with 186,000 Fcfa in scenario 1 and with 59,000 Fcfa in scenario 2. In scenario 1, cereal crops were the main net income source for farm type 1 to 5 with a contribution of 70%, 69%, 46%, 36%, 43% to the net income respectively. In particular, maize (34%) and rice (36%) made up the biggest proportions of the net income for the farm type 1 and 2 respectively. Conventional cotton contributed 38% of the net income for the farm type 3. Peanut was the main net income source for the farm type 4 and 5 with a contribution of 27% and 36% to the net income respectively. In scenario 2, cotton contributed 29%, 45%, 72%, 47% and 44 % of the net income for the farm type 1 to 5 respectively. Peanut was the second most important crop for generating income for the farmers, followed by rice. In both scenarios, the contribution of the organic cotton to the farm net income was bigger for the farm type 5 than for the other farm types.

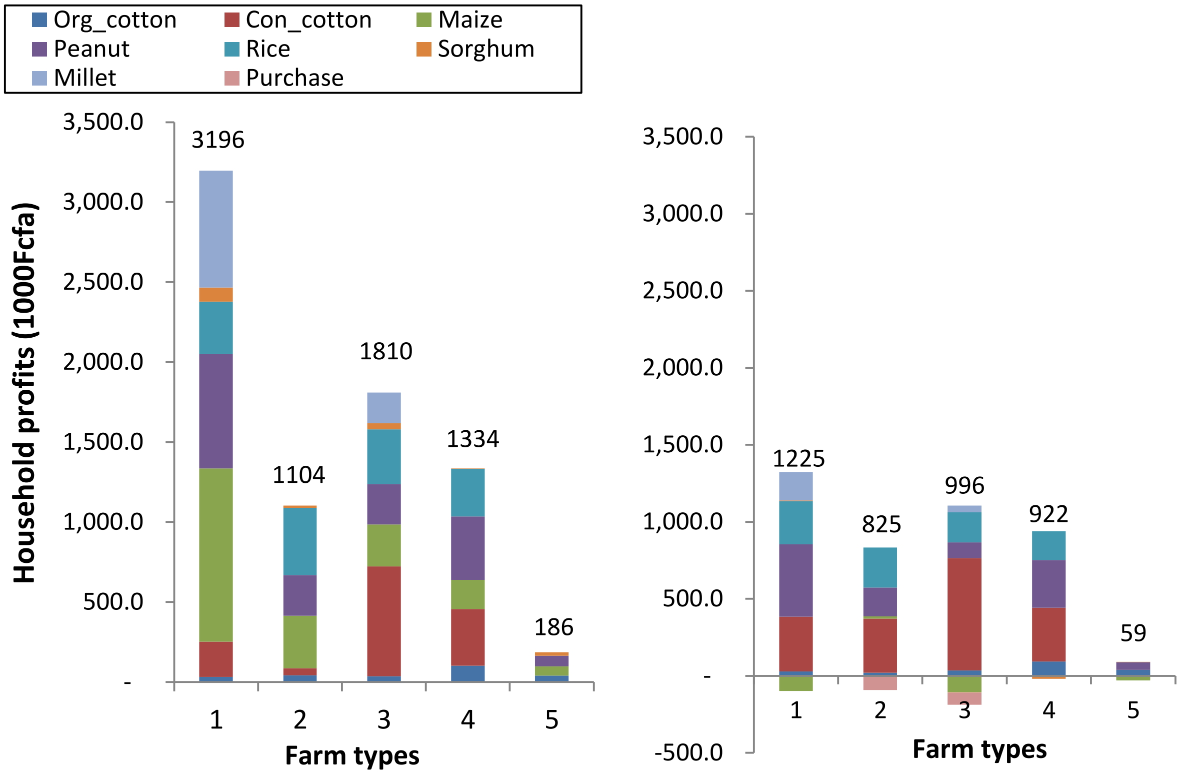


Figure 8. Average household profits by five farm types in scenario 1 (left) and scenario 2 (right) in 2013. N=2, 2, 4, 3, 1 respondents for each farm type respectively. The negative bar indicates the deficit net income for the crop (due to the cost of chemical fertilizers and chemicals) and the costs associated with the purchase of maize on the market.

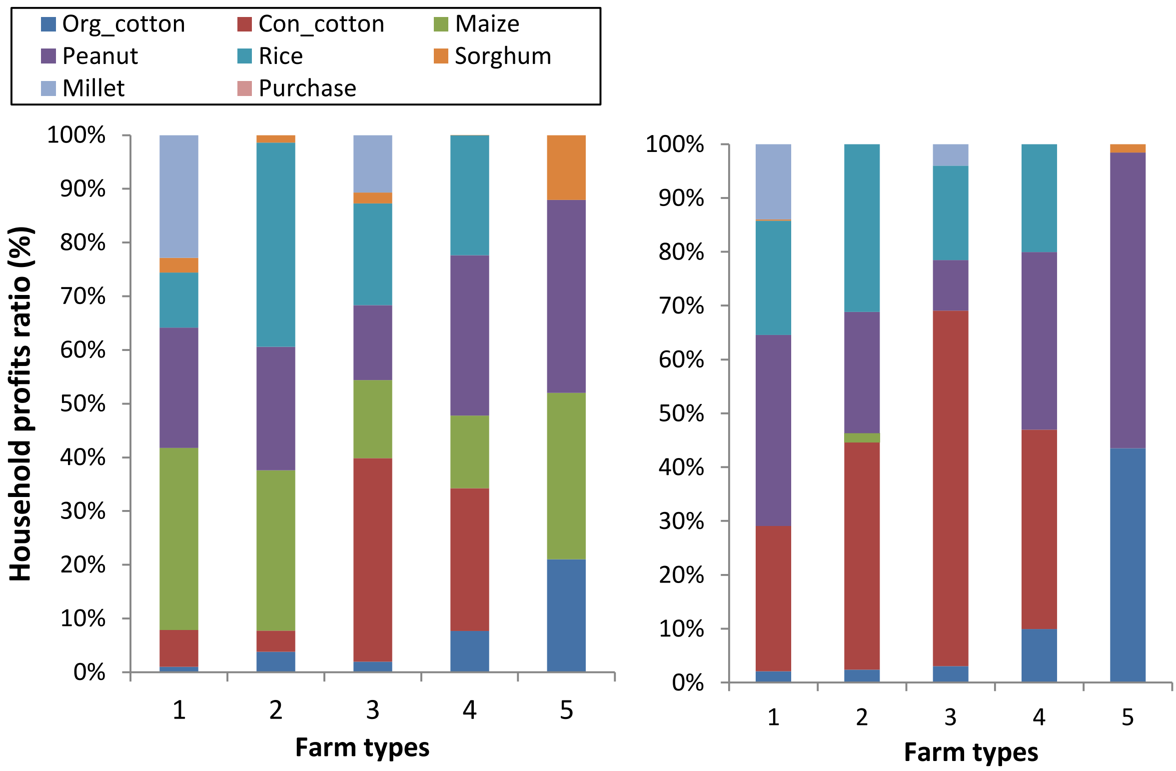


Figure 9. Average household profits composition ratio for five farm types in scenario 1 (left) and scenario 2 (right) in 2013. N=2, 2, 4, 3, 1 respondents for each farm type respectively.

3.3 Crop trials

3.3.1 Maize trials

The average grain yields were 1676, 1302 and 881 kg/ha for applying chemical fertilizers at full , half and zero of the recommended dose accompanied with compost application respectively, and 1284, 1105 and 674 kg/ha without compost application respectively (Figure 10). The average stover yields were 2391, 2205 and 1716 kg/ha for applying chemical fertilizers at full, half and zero of the recommended dose accompanied with compost application respectively, and 2146, 2024 and 1710 kg/ha without compost application respectively (Figure 11).

The maize grain yields were significantly higher for the fertilizer treatment at the full-recommended fertilizer doses than for the treatment without mineral fertilizers application ($P<0.05$). No significant difference was found for the stover yields at the three chemical fertilizer doses ($P>0.05$). Applying compost (6000 kg/ha) had no significant effect on the grain and stover yields ($P>0.05$).

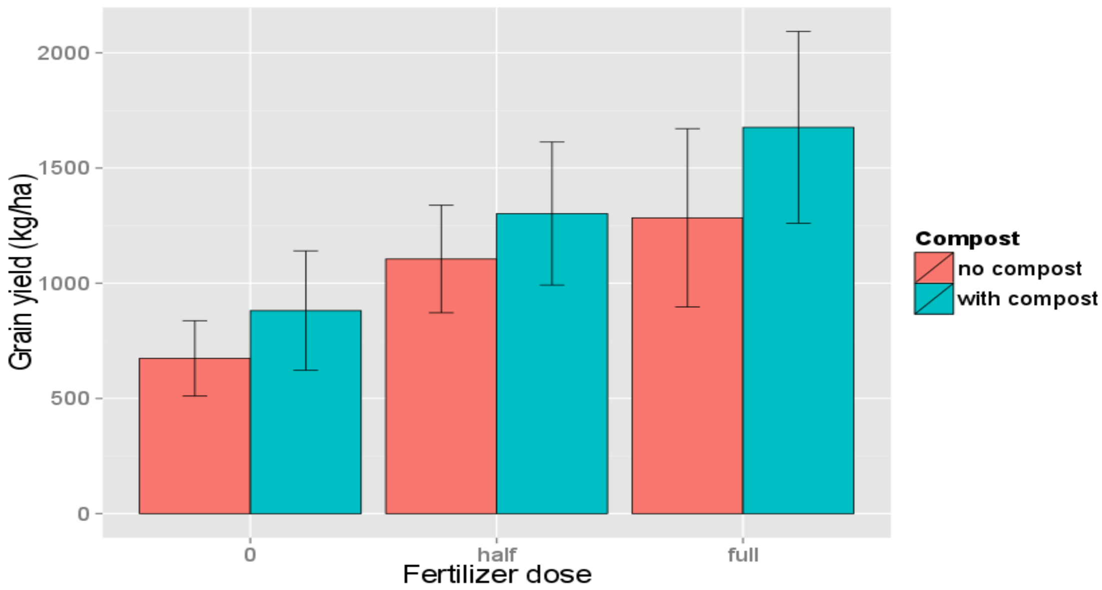


Figure 10. Maize grain yield (kg /ha) in four villages in 2014. Error bars are means ± standard error. N = 17 trials.

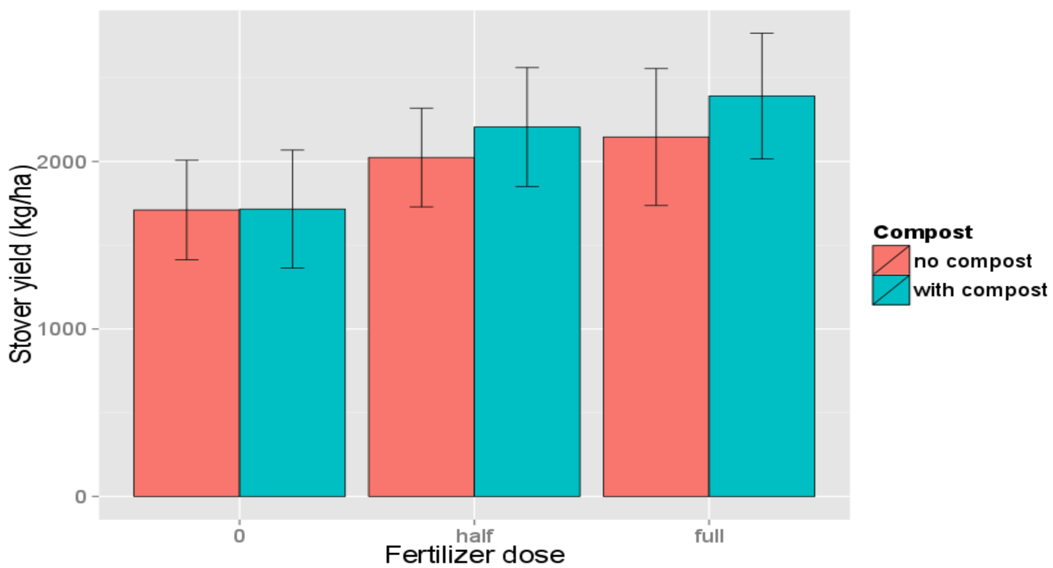


Figure 11. Maize stover yield (kg/ha) in four villages in 2014. Error bars are means ± standard error. N = 17 trials.

3.3.2 *Cowpea trials*

The average grain yields were 147, 65 and 0 kg/ha with the wulibali, local and dunanfana variety respectively accompanied with neem treatment, and 85, 40 and 0 kg/ha without neem treatment respectively (Figure 12). The average haulm yields were 4663, 2651 and 1118 kg/ha with the dunanfana, local and wulibali variety respectively accompanied with neem treatment, and 4222, 2621 and 1405 kg/ha without neem treatment respectively (Figure 13).

The cowpea grain yields with the wulibali variety were not significantly different from with the local variety (P>0.05) but were significantly higher than the dunanfana variety (P<0.05). The cowpea haulm yields with the dunanfana variety were significantly higher than with the local and wulibali variety (P<0.05). Spraying neem at every 7 days from the floral initiation to the pod maturity had no significant effect on both cowpea grain and haulm yields (P>0.05). However, neem insecticides may increase the grain yields with the wulibali variety to a large extent.

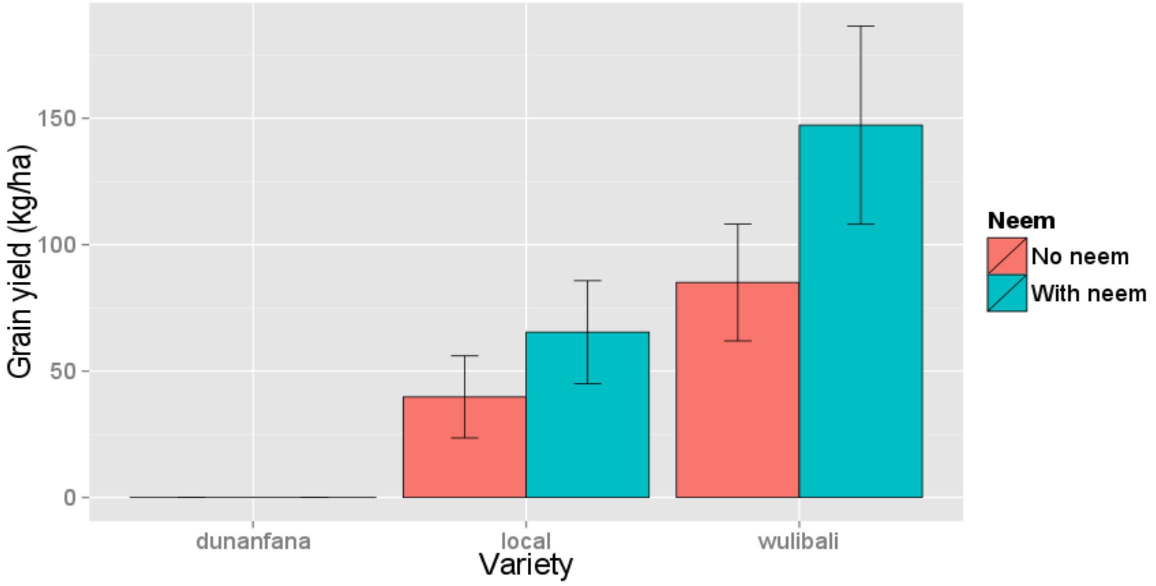


Figure 12. Cowpea grain yield (kg/ha) in four villages in 2014. Error bars are means ± standard error. N = 19 trials.

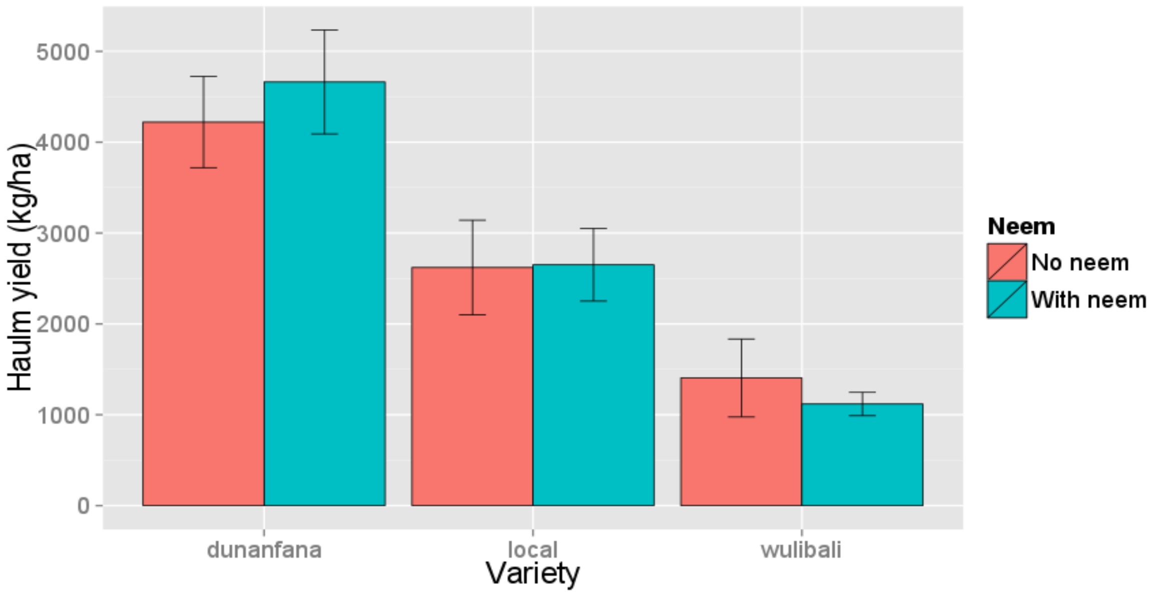


Figure 13. Cowpea haulm yield (kg/ha) in four villages in 2014. Error bars are means ± standard error. N = 19 trials.

3.3.3 Soybean trials

The average grain yields were 362 and 320 kg/ha for applying compost at a rate of 4000 kg/ha and no compost application accompanied with seed inoculation respectively, and 364 and 285 kg/ha without seed inoculation respectively (Figure 14). The average haulm yields were 438 and 271 kg/ha for applying compost at a rate of 4000 kg/ha and no compost application accompanied with seed inoculation respectively, and 477 and 362 kg/ha without seed inoculation respectively (Figure 15).

Applying compost at a rate of 4000 kg/ha and adopting seed inoculation had no significant effect on the soybean grain and haulm yields (P>0.05).

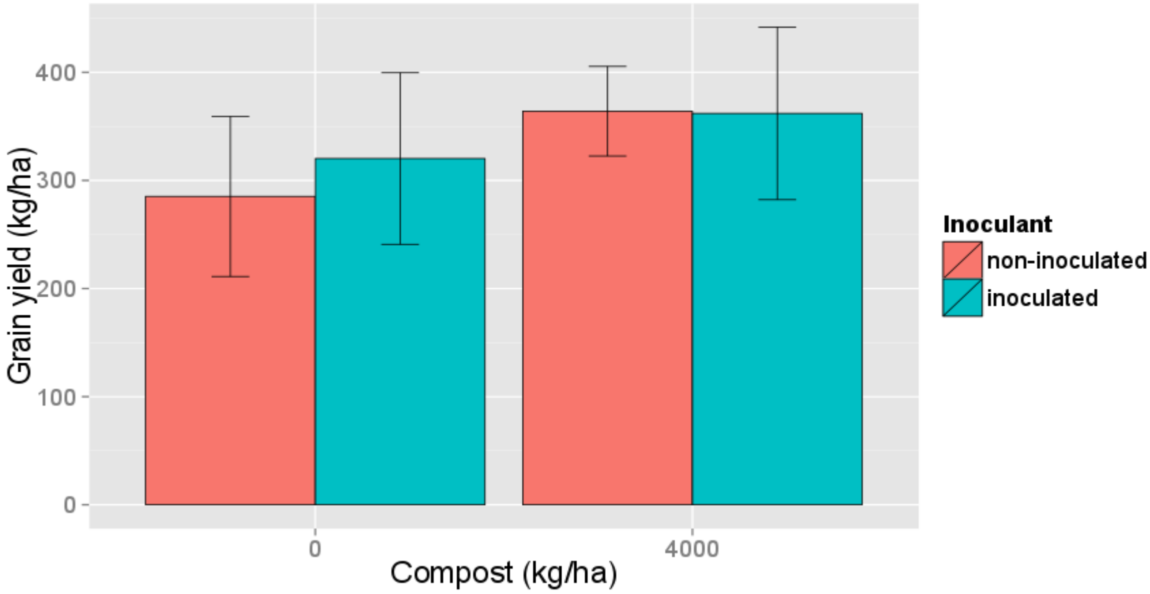


Figure 14. Soybean grain yield (kg/ha) in four villages in 2014. Error bars are means ± standard error. N = 8 trials.

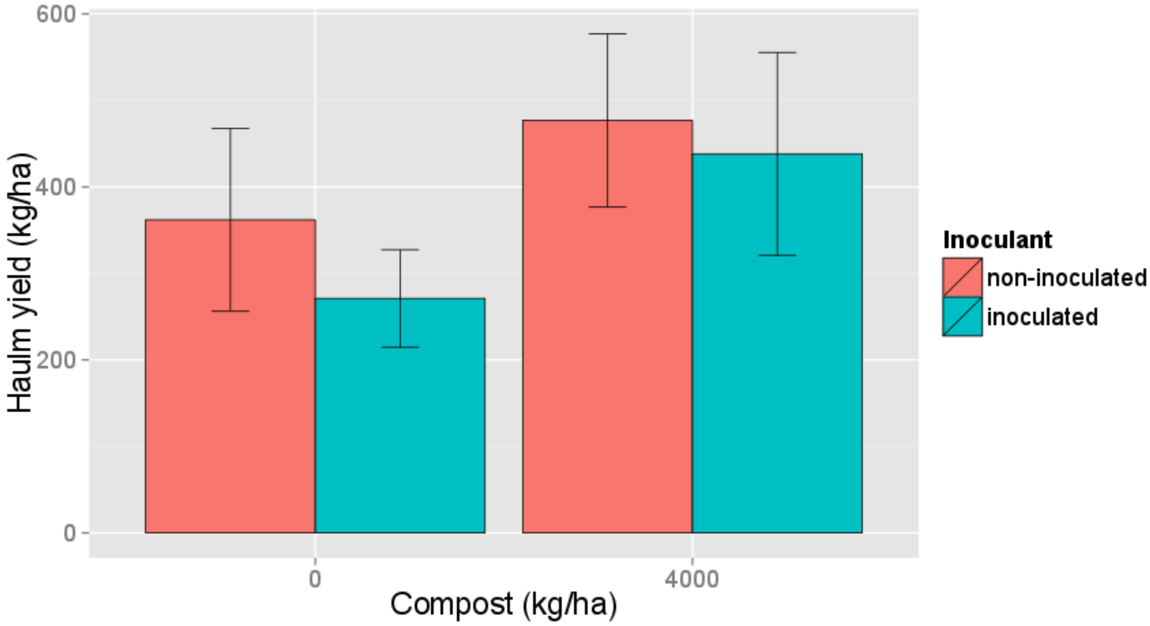


Figure 15. Soybean haulm yield (kg/ha) in four villages in 2014. Error bars are means ± standard error. N = 8 trials.

3.3.4 Sorghum and cowpea intercropping trials

In both cropping arrangements, the land use advantage of intercropping over sole cropping was evident for both the local and dunanfana variety treatments (total LER >1). The sorghum grain yields were 20-30% higher for the additive intercropping compared to the sole cropping for both cowpea varieties treatments. In addition, for the replacement intercropping, the total LER with the dunanfana variety was higher than with the local variety, and the pLERs and pLERc with the dunanfana variety was higher than with the local variety. The pLERc was nearly 50% lower for the additive intercropping pattern than for the replacement intercropping (Table 10).

Table 10. Sorghum and cowpea yield (kg/ha) and land equivalent ratio (LER) under different cropping systems and cowpea varieties in 2014. N = 5 trials. pLERs indicates partial land equivalent ratio of sorghum and pLERc indicates partial land equivalent ratio of cowpea haulm.

Treatment		Yield (kg/ha)				LER		
Cropping system	Cowpea variety	Sorghum grain		Cowpea haulm		pLERs	pLERc	Total LER
		mean	*SD*	mean	*SD*			
Sole cropping	local	187	*153*	2629	*1710*	n.a.	n.a.	n.a.
	dunanfana	187	*153*	6441	*4614*	n.a.	n.a.	n.a.
Additive intercropping	local	252	*195*	708	*750*	1.4	0.2	1.6
	dunanfana	221	*146*	3283	*4081*	1.3	0.4	1.7
Replacement intercropping	local	140	*151*	1441	*1820*	0.7	0.5	1.2
	dunanfana	151	*80*	4589	*3377*	1.0	0.7	1.7

3.3.5 *Profits analyses of the crop trials*

Table 11 provides a detailed profits analyses for different crop trials. Applying chemical fertilizers at half the recommended dose to the maize could generate at least 10,000 Fcfa more compared to not applying chemical fertilizers, and by applying compost at a rate of 6,000 kg/ha, an increase of gross margin by at least 20,000 Fcfa could be achieved compared to not applying compost. Assumed that all of the cowpea fodder could be sold on the market, farmers' earnings could be increased by more than 100,000 Fcfa by using the dunanfana variety as compared to the local variety, and an extra neem treatments could even increase the profits by about 15,000 Fcfa. Applying compost at a rate of 4,000 kg/ha to the soybean could increase the profits by at least 10,000 Fcfa compared to the treatments without compost. For the intercropping trials, the profitability of both intercropping patterns could be increased by more than 150,000 Fcfa by using the dunanfana variety compared to the local variety.

Table 11. Average crop yields, variable costs, revenues and gross margin. N= 17, 19, 8, 5 trials for maize, cowpea, soybean and sorghum-cowpea intercropping respectively. Cost refers to the cost of the materials for each crop trial. Revenue was calculated based on the assumption that all the harvests were sold on the market.

crop	Treatment		Grain (kg/ha)	Fodder (kg/ha)	Cost (Fcfa)	Revenue (Fcfa)	Gross margin (Fcfa)
	compost	fertilizer					
maize	0	0	717	n.a.	15000	76710	61710
maize	0	half	1176	n.a.	52500	125804	73304
maize	0	full	1366	n.a.	90000	146134	56134
maize	6000	0	938	n.a.	15000	100313	85313
maize	6000	half	1386	n.a.	52500	148258	95758
maize	6000	full	1784	n.a.	90000	190838	100838
	variety	neem					
cowpea	local	no	42	2738	15000	215770	200770
cowpea	dunanfana	no	0	4435	15000	332605	317605
cowpea	wulibali	no	88	1451	15000	139617	124617
cowpea	local	yes	68	2770	35000	224836	189836
cowpea	dunanfana	yes	0	4898	35000	367382	332382
cowpea	wulibali	yes	152	1155	35000	139910	104910
	compost	inoculant					
soybean	0	no	294	n.a.	56250	69105	12855
soybean	4000	no	375	n.a.	56250	88191	31941
soybean	0	yes	330	n.a.	56250	77601	21351
soybean	4000	yes	373	n.a.	56250	87714	31464
	cropping system	cowpea variety					
sorghum-cowpea	sole sorghum	n.a.	193	n.a.	1500	18528	17028
sorghum-cowpea	sole cowpea	local	n.a.	2739	15000	205425	190425
sorghum-cowpea	sole cowpea	dunanfana	n.a.	6780	15000	508500	493500
sorghum-cowpea	additive intercrop	local	260	738	9500	80296	70796
sorghum-cowpea	additive intercrop	dunanfana	228	3456	21500	281112	259612
sorghum-cowpea	replacement intercrop	local	144	1502	9500	126446	116946
sorghum-cowpea	replacement intercrop	dunanfana	156	4830	21350	377236	355886

4. Discussion

4.1 Farm typology

Alvarez et al. (2014) proposed a six-step framework to construct a farm typology, including objective statement, hypothesis formulation, data collection, key variables selections, multivariate statistics analysis, hypothesis verification. In this study, the main steps taken for typology making follow the similar pattern described by Alvarez et al. (2014). It was worth noting that several key resources variables (resource and asset related variables) were determined to give a reasonable indication on the crop management. A typology based on farmers' resources or assets was also favored by other reserachers (Köbrich et al., 2003; Zingore et al., 2007; Sanogo et al., 2010; Giller et al., 2011; Righi et al., 2011; Vanlauwe et al., 2014). As shown in Figure 3 and Figure 4, a two-step multivariate statistics analysis was conducted, including principal component analysis and cluster analysis. This two-step approach was also found in other typology studies in the context of Southern Mali (Sanogo et al., 2010; Dossa et al., 2011; Timler et al., 2014).

In this paper, farm type 1 had the largest number of workers, land and livestock, suggesting they were more likely to achive a higher crop production compared to other farmer types. Farm type 2 and 4 had more equipment per hectare of land compared to the households of other farm types, indicating these farmers were more likely to prepare the land and manage the crop in a timely manner on a consistent basis. Farm type 3 and 5 had fewer animals per hectare; therefore they had to either find a partner to pool the equipment or to borrow a whole set of cultivation or draft tools from other farmers. It was nearly impossible to borrow these tools at the peak periods of the growing season; hence these farmers were more likely to miss the timeliness for the land preparation and crop management. Farm type 5 had more family workers per hectare of land compared to the other farm types, suggesting they were either subsistence oriented crop farmers or hired laborers of the other farms who had fewer family workers.

In the process of typology making, one challenge occurred as to determining the suitable criteria and thresholds that could constitute a decision tree for household classification in one of the types. In this study, farm types 1 to 3 were classified by the criteria of total land size, herd size and the number of workers and only farm types 4 and 5 were classified by the criteria associated with the equipment – the number of carts (Figure 5). Even though MoBiom staff pointed out that it would be more functional and applicable if the equipment criteria were defined for all the farm types, we decided to use the number of carts only for classifying farm types 4 and 5. This was mainly due to the difficulties in determining the clear break points among the five farm types by equipment variables because of the large variances of the data.

Afterwards, a farm-type specific cotton profitability analysis was presented (Table 7). The results suggested that a farm typology indeed added insights to the analysis of profitability of the cotton production, especially in the context of Southern Mali, where enormous variability occurs among the farmers. However, based on the organic cotton yields in 2013 (Table 7), farm type 2 and 4 who had more oxen and tools per hectare of land reaped lower yields compared to farm type 1, 3 and 5. Aggregating farmers' yields from five years with more observations allowed us to minimize the variability of farmers' management among different years and to provide more convincing indications. The reduction of the organic cotton yields resulting from erratic rainfall could be considered as an external factor. However, as the data for the farmers was derived from the same region, the yield variation between different farmers was not so much due to differences in rainfall but rather caused by differences in management. Thus, it was more likely to believe that the yield variation among the different farmers was mainly caused by management. As shown in Figure 7, the five years' median yields for farm type 2 and 4 were higher than for farm type 1, 3 and 5, providing a better indication that farm typology was predictive in a multiple-year basis as more resources indicate higher odds of timely management.

In this case, it was difficult to reveal either farmer's preferences or crop productivity for the crop trials from a perspective of farm typology. The implications of farmer's resources for the crop yields were limited; since the materials for the crop trials such as fertilizers were provided to the farmers by the project. Besides, the small plot size was incapable to fully explain the constraints confronted by the farmers such as labor shortage.

4.2 Cotton production and profits analyses

The average land size of the organic cotton was less than 0.6 ha (Table 7), suggesting that farmers considered organic cotton as an alternative crop option rather than a prime choice. Organic cotton was more acceptable by the farmers before 2011; afterwards, there was a clear declining trend with high dropouts of farmers in three villages (Figure 6). The low yields of the organic cotton were likely caused by insufficient inputs of compost or manure (Table 6). The two main reasons that farmers applied few or no organic fertilizers to the organic cotton were lack of equipment and labor constraints.

There was a central pit in each village for depositing household waste, crop residues and garbage, which was the main source of organic fertilizer for the organic cotton. Some farmers also had their own compost piles close to their houses. One respondent even mentioned that he made a compost pile near the organic cotton field. It was worth mentioning that farmers barely manage to apply manure to the organic cotton fields, thus the implications of the household's livestock ownership (Table 4) were limited. Eventually, farmers' decisions on the application of the organic fertilizer were determined by the availability of the draft tools and laborers.

Type 5 farmer didn't grow conventional cotton (Table 7). Type 5 farmers had fewer resources, while conventional cotton certainly demanded high amounts of fertilizers and chemicals in order to achieve reasonable yields. Table 3 showed that the total costs of fertilizers and chemicals per hectare for the conventional cotton was nearly 40 times higher than for the organic cotton. As cotton production is a "risky business" because of erratic rainfall and pest damage, the fact that fewer inputs were required for the organic cotton also reduces the risk of indebtedness as cotton inputs were typically acquired on a credit basis.

There was no hired labor cost for farm type 3 and 5 (Table 7), which might be explained by their availability of more family workers per hectare of land compared to other farm types (Table 4). By contrast, farm type 4 spent more cash on the hired labor possibly due to the labor shortage. Organic cotton bears at least four times higher equipment amortization costs than conventional cotton for farm type 1, 2 and 3, mainly due to the cost of sprayers. It was not allowed to use the same sprayer with chemicals that was used for conventional cotton, thus an additional sprayer was required. Farm type 1, 2 and 3 tend to purchase a new sprayer just for the organic cotton while farm type 4 stated that one common sprayer for the organic cotton was shared between up to five farmers. Indeed, the land size of the organic cotton was less than 0.6 ha for all farm types (Table 7), thus it was not worthwhile purchasing a new sprayer just for the organic cotton.

Although the selling price of the organic cotton was higher than the conventional cotton due to a premium price of 50 Fcfa/kg, the nearly two times lower net income of organic cotton compared to the conventional cotton is mainly caused by the lower yields of the former (Table 7). The results from this study was in line with Lakhal et al. (2008), who also found that farmers in Mali were unlikely to reap higher gross margins from organic cotton under the current low yield situation. Eventually, conventional cotton was able to generate more net income on a per worker basis than the organic cotton for farm type 1 to 4, indicating that the organic cotton demanded more labor inputs (Table 7). In terms of the organic cotton profitability per hectare, farm type 5 reaped a higher net income than the farmers of the other types, mainly due to the higher yields accompanied with the low variable and amortization costs of the animals and equipment. The respondent claimed that the cotton management like weeding and ridging was done by hand instead of harnessing a set of oxen with weeder or ridger. Lack of equipment didn't necessarily result in poor yields, as appropriate and timely management was the key to a high yield of organic cotton.

In terms of the annual maintenance and fixed costs for the draft animals and equipment, the gross margin analysis of this study took little account of the required working hours of each animal or equipment for the crops. In Bougouni, not just did the farmer himself use the tools or animals, but also his brothers, other relatives and friends in the village. Therefore reliable information of the precise working hours of the equipment or animals for the crops was difficult to gather. Another dilemma for the profits analyses was how to calculate the costs of the equipment and draft animals. The salvage value of oxen was assumed to be zero, but in some cases, farmers also sold the meat on the market in a much cheaper price. There was a missing part in the farmers survey regarding the destiny of the oxen, i.e. whether the died oxen was slaughtered for sale and consumption or was disposed of with no economic value, which should be addressed in the profits analyses in future studies. The annual maintenance costs of the equipment or draft animals were calculated based on the costs of annual maintenances whereas the amortization costs was calculated based on the costs that were spread out over the long term. It was not advisable to consider the annual costs or the amortization costs alone. In fact, farmers spent money on the equipment or draft animals for its failure to work so that the time of maintenance varied from 1 year to 5 years or even longer depending on the frequency and the way the equipment or draft animals were harnessed. Therefore, we included both the annual maintenance and the amortization costs in order to minimize the risk of misestimating the costs of the equipment or draft animals.

As shown in Figure 8 and Figure 9, farmers showed a tendency to diversify the crop production with a prime choice of maize and cotton complemented with rice, peanut and other crops. Assuming all the harvests were sold on the market directly, cereals were the main net income source, while it shifted to cotton when taking into account the household food consumption (Figure 9). In agreement with our observations, Laris & Foltz (2014) reported that since the 1980s, farmers shifted their focus from extensive sorghum and millet production to a more intensive system in which maize and cotton were grown annually in combination with other crops. Laris et al. (2015) noted that farmers in southern Mali increasingly shifted chemical fertilizers allocation from the cotton to the grain crops since the 1990s due to the low price and late payment of the cotton. As a result, the maize grain yields increased at an average rate of over 2% from 1991 to 2007 (Foltz et al., 2012; Kelly et al., 2013). Mobiom staff also mentioned shifting fertilizer application practices when we presented our preliminary results of profits analyses. However, the respondents didn't report such practices to us.

Three studies reported that organic cotton was able to generate 10-20% higher profits for the farmers than the conventional cotton in the context of India and Kyrgyzstan because the premium price and low investment costs were able to offset the 10-20% lower yields of the organic cotton (Panneerselvam et al., 2010; Rieple & Singh, 2010; Bachmann, 2012). Two studies found that organic cotton was not profitable compared to conventional cotton because the yields of organic cotton was at least 50% lower than that of conventional cotton in the context of Benin and Mali (Lakhal et al., 2008; Kloos & Renaud, 2014). The results of this study were in line with the latter two studies, suggesting organic cotton was not economically viable as conventional cotton due to the large yield difference between the two. However, the studies mentioned above barely took into account the heterogeneity of farmers when analysing the cotton profits at the regional or country level. Since these studies barley harnessed a proper typology and systems research approach, only limited broader conclusions and policy recommendations can be drawn from their findings (Dossa et al., 2011). Also, few of these studies addressed the issue of fixed costs and variable costs in detail. The method used in this study was novel in that it accounts for farm diversity through a transparent and step-wise procedure, which combines a farm typology with a gross margin analysis.

4.3 Crop trials

Maize grain yields responded positively with increasing fertilizer applications in a cost-effective way (Table 11). In accordance with the results reported by several studies in Southern Mali (Diallo, 2011; Foltz et al., 2012; Coulibaly et al., 2014; Laris & Foltz, 2014; Laris et al., 2015), the results from this study also found that chemical fertilizers application served as the main factor that drives maize yields with little impact from compost (Figure 10).

Cowpea grain yields were rather low while the haulm yields were very high in 2014. Pod borers, aphids and thrips infestations as well as natural enemies such as ladybugs were observed in farmers' fields during the field visits, which might cause such low grain yields. Two studies showed that neem extracts significantly increased cowpea grain yields through thrips control (Saxena & Kidiavai, 1997; Tanzubil, 2008), and two other studies found more widely varying effects on cowpea grain yields (Bottenberg & Singh, 1996; Cobbinah & Osei-Owusu, 2011). The results from this study were in agreement with the latter two studies, which showed that neem could increase grain yields but with large variability (Figure 12). Bottenberg & Singh (1996) noted that inconsistent yield improvements might result from uneven coverage of cowpea plants and variability in amounts of neem sprayed.

Soybean grain yields were still very low compared to the yields reported by other studies (Devlin et al., 1995; Kwari & Kamara, 2011; Popovic et al., 2013; Herrmann et al., 2014). Seed inoculant had no significant effect on the increase of grain yields, which was in accordance with the results reported by Laditi & Nwoke (2012). However, research done by Mutuma et al. (2014) in Kenya reported that there was a significant increase in grain yields for the inoculant users compared to the non-users. Botha et al. (2004) also noted that seed inoculant could significantly increase the grain yields only when soil pH was in favorable conditions (pH 5 - 7). During the field visits, it was observed that non-inoculated soybean could form the root nodules without seed inoculation, suggesting the promiscuity with indigenous rhizobia favoring the formation of root nodules.

As shown in Table 10, the yield advantages of sorghum-cowpea intercropping over sole cropping was evident, which was in accordance with the findings of other legume-cereal intercropping studies (Pal et al., 1993; Naim et al., 2013). Carsky et al (1994) reported that planting the cowpea and sorghum in the same row or in the same hills could reduce striga density and numbers of striga per sorghum stand, which might explain that sorghum grain yields were higher for the additive intercropping than for the sole cropping in this study (Table 10). The generally low yields were likely caused by the poor soil fertility of some farmers' fields (Timler et al., 2014) as well as bird damage reported by the farmers during the field visits.

The yield variation in different crops (high for maize, low for other crops) might reflect farmers' preferences as maize trials were commonly located close to the inhabited areas with richer soil fertility and other crop trials were installed in the marginal un-responsive lands with low soil fertility. The labor availability at the peak periods was limited, e.g., rainy season. Since farmers reaped less benefits from the small-sized trials compared to their own crop fields, it would be more likely that farmers allocated more laborers and time on their own fields. Farmers put emphasis on maize because they could reap more benefits from it such as higher grain yields and the carry-over effects of fertilization. During the field visits, we observed that most cowpea, soybean and intercropping trials were located far away from the homesteads. This hindered the monitoring work by contact person and technicians. Fluctuating prices of cowpea and soybean through the year combined with its poor yields eventually disrupted farmer's interest in the management of crop trials.

Analyzing the agro-ecological intensification packages from a farm typology perspective proved to be difficult due to the poor compatibility in crop trials and farm typology, which means that the implementation of crop trials was open to the farmers in general rather than to specific target group of farmers, e.g., farmers with low resource endowments. Blazy et al. (2009) proposed a stepwise framework to design an alternative crop management system (CMS) that takes into account the diversity of farms. Step 1: farm typology construction. Step 2: prototyping innovative CMS with expert participation. Then, the compatibility indicators were evaluated by the experts to show the suitability of each innovation for different farm types. Lastly, Blazy et al. (2009) suggested to develop a model and to incorporate it with the prototyping process in order to assess the prototypes' impacts on each farm type. This prototyping framework is also used by other researchers, e.g., (Sterk & Ittersum, 2007; Ittersum et al., 2008).

Based on the farm typology and crop trials results, the selected crop systems innovations in terms of their fit within five farm types were explored through part of the above prototyping framework of Blazy et al. (2009). The following steps were conducted: (1) Define the objectives; (2) Explore options for a change of farming systems specified for each farm type. In the first step, the objective was to increase the adoption rate of agro-ecological intensification techniques. In the second step, different options specified for each farm type were explored based on the experimental results and by checking related studies done in Mali or in a similar context.

As one of the major cereal crops in Southern Mali, maize plays a critical role in safeguarding food security of the smallholder farmers. It enjoys preferences by farmers due to its marketability through the season, high productions, rapid maturity and low labor requirements (Laris & Foltz, 2014).

Although it requires fertilizer inputs, farmers from different farm types could still reap the benefits from cultivating maize, especially farm type 1 and 2. Since farm type 1 and 2 are able to take a risk of growing a large area of cotton due to their higher resource endowment compared to farm type 3, 4 and 5, they could get more fertilizers from CMDT to fulfill their intentions of intensifying maize production. Penning animals on crop fields or collecting manure are also feasible options for farm type 1, 2 and 4 as they had more animals per hectare than other farm types (Table 4).

Cowpea is an important legume crop that fixes nitrogen and has a high adaptability to less fertile soils and erratic rainfall (Chikoye et al., 2014). Phosphorus deficiencies was one of the reasons that limit legume productivity as the process of nitrogen fixation requires phosphorus (Tefera, 2011). When the accessibility to chemical fertilizers was limited, Tilemsi phosphate rock might provide a widely applicable approach for farm type 1, 2, 3 and 4 due to its lower price and availability in Mali (Bationo et al., 1997; Babana & Antoun, 2006). As type 5 farmers only have a small piece of arable land (Table 4), the adoption of sole legume cropping might be unfeasible. In Nigeria, Ivbijaro & Bolaji (2009) reported that neem extracts in combination with chemical pesticides (cypermethrin, dimethoate) could significantly reduce number of thrips, pod borers and pod-sucking bugs, resulting in higher cowpea grain yields. It is feasible to test the combination of bio- and chemical-insecticides treatment at different doses for farm type 1 to 4. Due to the limited number of household workers per hectare, farm type 2 and 4 might confront the constraints of weed management (Table 4). Manual weeding was time-consuming, expensive and inefficient (Chikoye et al., 2006). Labor availability at the peak periods of the growing season was limited. Chikoye et al. (2014) reported that herbicides (imazaquin, pendimethalin) sprayed at lower doses could significantly reduce weed biomass compared to the un-weeded control while it had little impact on the vesicular arbuscular mycorrhizal fungi species richness and amounts of fixed nitrogen, and eventually yielded higher cowpea grains than un-weeded control. Hence, combining low-dose herbicides with manual weeding could be explored for farm type 2 and type 4.

Soybean is a protein-rich crop, which was new to the farmers in Bougouni. It would be interesting to explore the yield performance of different varieties that were released recently by International Institute of Tropical Agriculture (IITA) (Gros, 2015), as it seems that the variety used in our trials yielded very poorly. It might be unfeasible for farm type 5 to adopt the sole soybean cropping, for the same reason as the sole cowpea. In addition, the claimed benefits of manure application could be explored in future studies (Powell & Mohamed-Saleem, 1987; Sanginga, 2003; Bationo et al., 2007), especially for farm type 1 and 2 who had large livestock (Table 4).

Although intercropping had a higher land use advantage over sole cropping, the higher labor demands for management compared to the sole crops should not be ignored (Waddington et al., 2007; Rusinamhodzi & Corbeels, 2012). This technique was suitable for farm type 5 as they had fewer lands and more laborers (Table 4). A soybean-maize or soybean-sorghum intercropping could be explored for farm type 5. This intercropping regime was tested by researchers in various contexts (Wahua & Miller, 1978; Ahmed & Rao, 1982; Makena & Doto, 1982; Ofori & Stern, 1987; Li et al., 2003; Hauggaard-Nielsen et al., 2008) and the results showed that intercropping had a land use advantage over the sole cropping. It would be interesting to explore the potential of yields improvements with additive intercropping at different spatial arrangement to test grain yield performance, e.g., a row of the alternated sorghum-soybean crop and a row of sole sorghum or sole soybean arranged at different patterns like 1:1, 1:2, 2:1, 2:2, etc., (Naim et al., 2013).

5. Conclusion and recommendation

Farm typology provided a structural framework to transform a heterogeneous farming system into a low-dimension and context-based partial representation of reality. This stepwise method was applicable in the context of Bougouni, where a large diversity of farms exists.

The five farm types identified in this paper mainly differed in number of workers, land area, herd size and number of equipment, which all had an effect on agricultural productivity and soil fertility management. The cotton land in particular had a substantial effect on the crop productivity and soil fertility management as fertilizer was typically acquired from CMDT that closely linked to the cultivated cotton area (Laris & Foltz, 2014). Conventional cotton was able to generate 2.4, 2.1, 1.5 and 1.6 times more net income than organic cotton for farm type 1, 2, 3 and 4. Due to the fact that the type 5 farmer reaped a higher yield and owned little livestock and equipment, he was able to gain more profits than the farmers of other types for organic cotton on a per hectare basis. Of all the farm types, farm type 5 gained the lowest profits when taking into account all the crops sale at the household level. Assuming that all the harvests were sold on the market, cereal crops were the main source of profits. When taking into account the household food consumption, cotton was the prime income generator for the farmers of each type.

There were few alternative approaches to replace bare hands for the managements of the organic cotton. Some farmers charged a small amount of money for lending a full set of cultivation tools and draft tools. It was also quite common among the cotton farmers in these villages to pool the draft animals and equipment. In future, the interventions could be paying more attention to providing an equipment scheme specifically targeting type 5 farmers. E.g., a common set of equipment could be provided to up to 5-10 famers. Type 5 farmers could also rent a set of equipment from other farmers in case that the common equipment was not available and the rent costs could be subsided by the local institutions.

Applying fertilizers at the full recommended doses could significantly increase the maize grain yields compared to not applying any chemical fertilizers. Adopting the dunanfana variety of cowpea could significantly increase the haulm yields compared to cultivating the local variety. Intercropping sorghum with cowpea showed a evident land use advantage over the sole cropping. Replacing low quality compost with manure to test its effect on the yield increase potential would be a feasible option to explore in future research. To test a combination of bio-pesticides and chemical pesticides at different doses would also be a feasible option for the cowpea.

Agroecological intensification might be one of the feasible approaches in the context of Southern Mali. Fitting different packages that were acceptable and applicable for this context (nature, institution and market configurations) while taking into account the large diversity of the farmers demanded a large investment of capital, time and expertise. Farm typology might be able to reduce this high demand to a large extent, although collecting information and testing different options at the regional level require a large amount of time. Furthermore, long-term studies with more observations may allow improved understanding if there are annual variations.

References

Abdulai, A., & CroleRees, A. (2001). Determinants of income diversification amongst rural households in Southern Mali. *Food Policy*, *26*(4), 437–452.

Ahmed, S., & Rao, M. R. (1982). Performance of maize—soybean intercrop combination in the tropics: Results of a multi-location study. *Field Crops Research*, *5*, 147–161.

Alvarez, S., Paas, W., Descheemaeker, K., Tittonell, P., & Groot, J. C. J. (2014). *Typology construction, a way of dealing with farm diversity: general guidelines for the Humidtropics*. *Report for the CGIAR Research Program on Integrated Systems for the Humid Tropics*. Wageningen.

Ayantunde, A. A., Asse, R., Said, M. Y., & Fall, A. (2014). Transhumant pastoralism, sustainable management of natural resources and endemic ruminant livestock in the sub-humid zone of West Africa. *Environment, Development and Sustainability*, *16*(5), 1097–1117.

Ba, A., Lesnoff, M., Poccard-Chapuis, R., & Moulin, C.-H. (2011). Demographic dynamics and off-take of cattle herds in southern Mali. *Tropical Animal Health and Production*, *43*(6), 1101–1109.

Babana, A. H., & Antoun, H. (2006). Biological system for improving the availability of Tilemsi phosphate rock for wheat (Triticum aestivum L.) cultivated in Mali. *Nutrient Cycling in Agroecosystems*, *76*(2-3), 285–295.

Bachmann, F. (2012). Potential and limitations of organic and fair trade cotton for improving livelihoods of smallholders: evidence from Central Asia. *Renewable Agriculture and Food Systems*, *27*(02), 138–147.

Bassett, T. J. (2010). Slim pickings: Fairtrade cotton in West Africa. *Geoforum*, *41*(1), 44–55.

Bationo, A., Ayuk, E., Ballo, D., & Koné, M. (1997). Agronomic and economic evaluation of Tilemsi phosphate rock in different agroecological zones of Mali. *Nutrient Cycling in Agroecosystems*, *48*(3), 179–189.

Bationo, A., Kihara, J., Vanlauwe, B., Waswa, B., & Kimetu, J. (2007). Soil organic carbon dynamics, functions and management in West African agro-ecosystems. *Agricultural Systems*, *94*(1), 13–25.

Bationo, A., Kimetu, J., Kihara, J., Traore, Z., Bagayoko, M., Bado, V., … Koala, S. (2012). Cropping Systems in the Sudano-Sahelian Zone: Implications on Soil Fertility Management over Varied Seasons. In A. Bationo, B. Waswa, J. Kihara, I. Adolwa, B. Vanlauwe, & K. Saidou (Eds.), *Lessons learned from Long-term Soil Fertility Management Experiments in Africa* (pp. 137–159). Dordrecht: Springer Netherlands.

Beaman, L., Karlan, D., Thuysbaert, B., & Udry, C. (2013). Profitability of Fertilizer: Experimental Evidence from Female Rice Farmers in Mali. *American Economic Review*, *103*(3), 381–86.

Benjaminsen, T. A. (2001). The population–agriculture–environment nexus in the Malian cotton zone. *Global Environmental Change*, *11*(4), 283–295.

Benjaminsen, T. A., Alinon, K., Buhaug, H., & Tove, J. (2010). Land Use Conflicts in the Inner Niger Delta of Mali : Does Climate Change Play a Role ? In *Climate Change and Security* (pp. 21–24). Trondheim: the Royal Norwegian Society of Sciences and Letters.

Benjaminsen, T. A., Aune, J. B., & Sidibé, D. (2010). A critical political ecology of cotton and soil fertility in Mali. *Geoforum*, *41*(4), 647–656.

Blanchard, M., Vayssieres, J., Dugué, P., & Vall, E. (2013). Local Technical Knowledge and Efficiency of Organic Fertilizer Production in South Mali: Diversity of Practices. *Agroecology and Sustainable Food Systems*, *37*(6), 672–699.

Blazy, J.-M., Ozier-Lafontaine, H., Doré, T., Thomas, A., & Wery, J. (2009). A methodological framework that accounts for farm diversity in the prototyping of crop management systems. Application to banana-based systems in Guadeloupe. *Agricultural Systems*, *101*(1-2), 30–41.

Botha, W., Jaftha, J., Bloem, J., Habig, J., & Law, I. (2004). Effect of soil bradyrhizobia on the success of soybean inoculant strain CB 1809. *Microbiological Research*, *159*(3), 219–231.

Bottenberg, H., & Singh, B. B. (1996). Effect of neem leaf extract applied using the “broom” method, on cowpea pests and yield. *International Journal of Pest Management*, *42*(3), 207–209.

Brock, K., Coulibaly, N., Ramisch, J., Wolmer, W., & Scoones, I. (2002). Crop-livestock integration in Mali: multiple pathways of change. In I. Scoones & W. Wolmer (Eds.), *Pathways of change in Africa: crops, livestock and livelihoods in Mali, Ethiopia and Zimbabwe* (pp. 33–90). Sussex: James Currey Ltd.

Carsky, R. J., Singh, L., & Ndikawa, R. (1994). Suppression of Striga hermonthica on sorghum using a cowpea intercrop. *Experimental Agriculture*, *30*(3), 349–358.

Chikowo, R., Zingore, S., Snapp, S., & Johnston, A. (2014). Farm typologies, soil fertility variability and nutrient management in smallholder farming in Sub-Saharan Africa. *Nutrient Cycling in Agroecosystems*, *100*(1), 1–18.

Chikoye, D., Abaidoo, R., & Fontem, L. A. (2014). Response of weeds and soil microorganisms to imazaquin and pendimethalin in cowpea and soybean. *Crop Protection*, *65*, 168–172.

Chikoye, D., Ellis-Jones, J., Kormawa, P., Udensi, U. E., Ibana, S. E., & Avav, T. R. (2006). Options for Cogongrass (Imperata cylindrica) Control in White Guinea Yam (Dioscorea rotundata) and Cassava (Manihot esculenta) 1. *Weed Technology*, *20*(3), 784–792.

Cobbinah, J. R., & Osei-Owusu, K. (2011). Effects of Neem Seed Extracts on Insect Pests of Eggplant, Okra and Cowpea. *International Journal of Tropical Insect Science*, *9*(05), 601–607.

Côte, F., Tomekpe, K., Staver, C., & Depigny, S. (2010). Agro-ecological intensification in banana and plantain (Musa spp.): an approach to develop more sustainable cropping systems for both smallholder farmers and large-scale commercial producers. In T. Dubois (Ed.), *ISHS Acta Horticulturae 879 on Banana & Plantain in Africa* (pp. 457–463). Leuven: International Society for Horticultural Science.

Cotton Incorporated. (n.d.). Cotton Entomology Insect Pest Management. Retrieved December 2, 2014, from http://www.cottoninc.com/fiber/AgriculturalDisciplines/Entomology/

Coulibaly, A. (2006). Country Pasture Profiles: Mali. Retrieved May 31, 2014, from http://www.fao.org/ag/AGP/AGPC/doc/Counprof/Mali/mali.htm

Coulibaly, J. Y., Sanders, J. H., Preckel, P. V., & Baker, T. G. (2015). Will cotton make a comeback in Mali? *Agricultural Economics*, *46*(1), 1–15.

Davey, L. E. (1979). A COMPARISON OF DEPRECIATION METHODS UNDER CURRENT COST ACCOUNTING. *Australian Journal of Agricultural Economics*, *23*(1), 37–47.

de Ridder, N., Breman, H., van Keulen, H., & Stomph, T. J. (2004). Revisiting a "cure against land hunger": soil fertility management and farming systems dynamics in the West African Sahel. *Agricultural Systems*, *80*(2), 109–131.

Defoer, T., Budelman, A., Toulmin, C., & Carter, S. E. (2000). Sources and flows of nutrients in farming. In T. Defoer & A. Budelman (Eds.), *Managing soil fertility in the tropics. Building common knowledge: participatory learning and action research.* (pp. 61–66). Amsterdam: Royal Tropical Institute, KIT Press.

Devlin, D. L., Fjell, D. L., Shroyer, J. P., Gordon, W. B., Marsh, B. H., Maddux, L. D., … Duncan, S. R. (1995). Row Spacing and Seeding Rates for Soybean in Low and High Yielding Environments. *Journal of Production Agriculture*, *8*(2), 215.

Diallo, A. (2011). *An Analysis of the Recent Evolution of Mali's Maize Subsector* (pp. 1–83). Michigan.

Dixon, J., Gulliver, A., & Gibbon, D. (2001). SUB-SAHARAN AFRICA. In M. Hall (Ed.), *Farming systems and poverty: improving farmers' livelihoods in a changing world* (pp. 29–83). Rome, Italy; Washington D.C., United States: Food and Agriculture Organization of the United Nations; World Bank.

Dossa, L. H., Abdulkadir, A., Amadou, H., Sangare, S., & Schlecht, E. (2011). Exploring the diversity of urban and peri-urban agricultural systems in Sudano-Sahelian West Africa: An attempt towards a regional typology. *Landscape and Urban Planning*, *102*(3), 197–206.

Dray, S., & Dufour, A. B. (2007). The ade4 package: implementing the duality diagram for ecologists. *Journal of Statistical Software*, *22*(4), 1–20.

Duguéa, P., Girarda, P., Bélièresb, J., & Havarda, M. (2008). Motorization in a cotton-growing region in Mali: Impact on functioning and flexibility of family farms. In *WS 3: Adaptive farming systems* (pp. 1–2). Clermont-Ferrand, France: International Farming Systems Association Europe Group.

Erenstein, O. (2006). Intensification or extensification? Factors affecting technology use in peri-urban lowlands along an agro-ecological gradient in West Africa. *Agricultural Systems*, *90*(1-3), 132–158.

FAIRTRADE. (2010). MOBIOM, Organic Cotton Co-operative, Mali. Retrieved July 18, 2014, from http://server-e9-11.hosting.imerja.com/producers/cotton/mobiom_mali_2.aspx?printversion=true

FAOSTAT. (2014). COUNTRY PROFILES: Mali. *FAO*. Rome: Food and Agriculture Organization, Statistics Division. Retrieved from http://faostat3.fao.org/home/E

Firth, C. (2002). The use of gross and net margins in the economic analysis of organic farms. In *Proceedings of the UK Organic Research 2002*. Aberystwyth, UK: Organic Centre Wales, Institute of Rural Studies, University of Wales.

Foltz, J. D., Aldana, U. T., & Laris, P. (2012). *The Sahel's Silent Maize Revolution: Analyzing Maize Productivity in Mali at the Farm-level* (No. 17801) (pp. 1–26).

Franke, A. C., van den Brand, G. J., & Giller, K. E. (2014). Which farmers benefit most from sustainable intensification? An ex-ante impact assessment of expanding grain legume production in Malawi. *European Journal of Agronomy*, *58*, 28–38.

Fuentes, P. A., Bumb, B., & Johnson, M. (2011). Improving Fertilizer Markets in West Africa: The Fertilizer Supply Chain in Mali. Retrieved December 23, 2014, from http://www.ifdc.org/r-d/research/mali_tech_final111913/

Giller, K. E., Tittonell, P., Rufino, M. C., van Wijk, M. T., Zingore, S., Mapfumo, P., … Vanlauwe, B. (2011). Communicating complexity: Integrated assessment of trade-offs concerning soil fertility management within African farming systems to support innovation and development. *Agricultural Systems*, *104*(2), 191–203.

Gros, A. (2015). Nigeria releases two soybean varieties developed at IITA - Press Release - IITA. Retrieved February 5, 2015, from http://217.77.189.136/web/iita/soybean-asset/-/asset_publisher/t3fI/content/nigeria-releases-two-soybean-varieties-developed-at-iita;jsessionid=A0E51FF41D49AEEAFFE685766884853D?redirect=%2Fweb%2Fiita%2Fsoybean#.VNOuTS6_bGw

Gueguen, J. (2010). Vers une maîtrise des filières céréalières par les Organisations Paysannes au Mali. Retrieved December 22, 2014, from http://www.afdi-opa.org/fr/images/uploaded/admin0509/Dossiers et analyses/Capitalisation cereales Gueguen 2010 V internet 2.pdf

Han, J., & Foltz, J. (2013). The Impacts of Weather Shocks on Child Mortality in Mali. Madison: University of Wisconsin-Madison, Department of Agricultural and Applied Economics.

HarvestChoice. (2011). AEZ Tropical (5-class). *HarvestChoice*. Washington DC, United Staes ;St. Paul, United States: International Food Policy Research Institute; University of Minnesota.

Hauggaard-Nielsen, H., Jørnsgaard, B., Kinane, J., & Jensen, E. S. (2008). Grain legume–cereal intercropping: The practical application of diversity, competition and facilitation in arable and organic cropping systems. *Renewable Agriculture and Food Systems*, *23*(01), 3–12.

Herrmann, L., Chotte, J. L., Thuita, M., & Lesueur, D. (2014). Effects of cropping systems, maize residues application and N fertilization on promiscuous soybean yields and diversity of native rhizobia in Central Kenya. *Pedobiologia*, *57*(2), 75–85.

ICRISAT. (n.d.). The West and Central Africa Semi-Arid Tropics (WCA-SAT). Retrieved December 4, 2014, from http://www.icrisat.org/icrisat-tools-wca.htm

Ittersum, M. Van, Ewert, F., & Heckelei, T. (2008). Integrated assessment of agricultural systems–A component-based framework for the European Union (SEAMLESS). *Agricultural Systems*, *96*(1), 150–165.

Ivbijaro, M. F., & Bolaji, O. O. (2009). Effects of cypermethrin + dimethoate and extracts of Piper guineense and Azadirachta indica on the pests and yield of cowpea, Vigna unguiculata. *The Journal of Agricultural Science*, *115*(02), 227.

Kabacoff, R. (2014). Advanced methods: cluster analysis. In *R in Action: Data Analysis and Graphics with R* (2nd ed., p. 475). New York: Manning Publications Company.

Kelly, V. A., Murekezi, A. K., Me-Nsope, N. M., Perakis, S. M., & Mather, D. (2013). *Cereal Market Dynamics: The Malian Experience from the 1990s to Present* (No. 146935). *Food Security International Development Working Papers* (pp. 1–137). Michigan State University, Department of Agricultural, Food, and Resource Economics.

Kevane, M. (1996). Agrarian Structure and Agricultural Practice: Typology and Application to Western Sudan. *American Journal of Agricultural Economics*, *78*(1), 236–245.

Kloos, J., & Renaud, F. G. (2014). Organic cotton production as an adaptation option in north-west Benin. *Outlook on Agriculture*, *43*(2), 91–100.

Köbrich, C., Rehman, T., & Khan, M. (2003). Typification of farming systems for constructing representative farm models: two illustrations of the application of multi-variate analyses in Chile and Pakistan. *Agricultural Systems*, *76*(1), 141–157.

Kouyaté, Z., & Diallo, D. (2012). Influence of crop management systems on soil properties and sorghum yields in the Sahelian zone of Mali. *African Journal of Agricultural Research*, *7*(37), 5217–5223.

Kumar, R. (2013). Mali Data Atlas, 26 April 2013 - Open Data for Mali. Retrieved December 23, 2014, from http://mali.opendataforafrica.org/bqrabjg/mali-data-atlas-26-april-2013?action=download

Kwari, J., & Kamara, A. (2011). Soil fertility variability in relation to the yields of maize and soybean under intensifying cropping systems in the tropical savannas of northeastern Nigeria. In *Innovations as key to the green revolution in Africa* (pp. 457–464). Springer Netherlands.

Laditi, M., & Nwoke, O. (2012). Evaluation of microbial inoculants as biofertilizers for the improvement of growth and yield of soybean and maize crops in savanna soils. *African Journal of Agricultural Research*, *7*(3), 405–413.

Lakhal, S. Y., Sidibé, H., & H'Mida, S. (2008). Comparing conventional and certified organic cotton supply chains : the case of Mali. *International Journal of Agricultural Resources, Governance and Ecology*, *7*(3), 243–255.

Lambin, E. F., D'haen, S. A. L., Mertz, O., Nielsen, J. Ø., & Rasmussen, K. (2014). Scenarios on future land changes in the West African Sahel. *Geografisk Tidsskrift-Danish Journal of Geography*, *114*(1), 76–83.

Landais, E. (1998). Modelling farm diversity. *Agricultural Systems*, *58*(4), 505–527.

Laris, P., & Foltz, J. D. (2014). Cotton as Catalyst? The Role of Shifting Fertilizer in Mali's Silent Maize Revolution. *Human Ecology*, *42*(6), 857–872.

Laris, P., Foltz, J. D., & Voorhees, B. (2015). Taking from cotton to grow maize: The shifting practices of small-holder farmers in the cotton belt of Mali. *Agricultural Systems*, *133*, 1–13.

Leighton, T., & Sacande, M. (2011). Developments - Ensuring the sustainability of organic cotton production in Mali. Retrieved July 19, 2014, from http://www.new-ag.info/en/developments/devItem.php?a=1892

Lélé, M. I., & Lamb, P. J. (2010). Variability of the Intertropical Front (ITF) and Rainfall over the West African Sudan–Sahel Zone. *Journal of Climate*, *23*(14), 3984–4004.

Li, L., Zhang, F., Li, X., Christie, P., Sun, J., Yang, S., & Tang, C. (2003). Interspecific facilitation of nutrient uptake by intercropped maize and faba bean. *Nutrient Cycling in Agroecosystems*, *65*(1), 61–71.

Makena, M. M., & Doto, A. L. (1982). Soybean-cereal intercropping and its implications in soybean breeding. In *Intercropping. Proceedings of the Second Symposium on Intercropping in Semi-Arid Areas, held at Morogoro, Tanzania, 4-7 August 1980.* (pp. 84–90).

Masters, W., Ghosh, S., Daniels, J., & Sarpong, D. (2013). *Comprehensive assessment of the peanut value chain for nutrition improvement in Ghana*. *sites.tufts.edu* (pp. 1–102). Boston.

Molua, E. L. (2010). Farm income, gender differentials and climate risk in Cameroon: typology of male and female adaptation options across agroecologies. *Sustainability Science*, *6*(1), 21–35.

Mutuma, S., Okello, J., Karanja, N., & Woomer, P. (2014). Smallholder farmers’ use and profitability of legume inoculants in western Kenya. *African Crop Science Journal*, *22*(3), 205–214.

Naim, A. M. E., Kilali, B. A., Hassan, A. E., & Ahmed, M. F. (2013). Agronomic Evaluation of Sorghum and Cowpea Intercropped at Different Spatial Arrangements. *Journal of Renewable Agriculture*, *1*(2), 11–16.

Nelson, V., & Smith, S. (2011). *Fairtrade Cotton: Assessing impact in Mali, Senegal, Cameroon and India* (pp. 49–66). London, United Kingdom; East Sussex. United Kindom.

Nijenhuis, K. (2013). *Farmers on the move: mobility, access to land and conflict in Central and South Mali*. Wageningen UR. Retrieved from http://library.wur.nl/WebQuery/clc/2043218

Ofori, F., & Stern, W. R. (1987). Cereal–Legume Intercropping Systems. *Advances in Agronomy*, *41*, 41–90.

Pal, U. R., Oseni, T. O., & Norman, J. C. (1993). Effect of component densities on the productivity of soybean/maize and soybean/sorghum intercrop. *Journal of Agronomy and Crop Science*, *170*(1), 66–70.

Panneerselvam, P., Hermansen, J. E., & Halberg, N. (2010). Food Security of Small Holding Farmers: Comparing Organic and Conventional Systems in India. *Journal of Sustainable Agriculture*, *35*(1), 48–68.

Poccard-Chapuis, R., Navegantes Alves, L., Grise, M. M., Bâ, A., Coulibaly, D., Ferreira, L. A., & Lecomte, P. (2014). Landscape characterization of integrated crop–livestock systems in three case studies of the tropics. *Renewable Agriculture and Food Systems*, *29*(3), 218–229.

Popovic, V., Malesevic, M., Miladinovic, J., Maric, V., & Zivanovic, L. (2013). Effect of agroecological factors on variations in yield, protein and oil contents in soybean grain. *Romanian Agricultural Research*, *30*, 241–247.

Powell, J. M., & Mohamed-Saleem, M. A. (1987). Nitrogen and phosphorus transfers in a crop-livestock system in West Africa. *Agricultural Systems*, *25*(4), 261–277.

Pretty, J., Toulmin, C., & Williams, S. (2011). Sustainable intensification in African agriculture. *International Journal of Agricultural Sustainability*, *9*(1), 5–24.

R Core Team. (2014). R: A language and environment for statistical computing. *R Foundation for Statistical Computing*. Vienna, Austria.: R Foundation for Statistical Computing. Retrieved from http://www.r-project.org/

Rao, M. R., & Willey, R. W. (1980). The Concept of a “Land Equivalent Ratio” and Advantages in Yields from Intercropping. *Experimental Agriculture*, *16*(03), 217–228.

Rieple, A., & Singh, R. (2010). A value chain analysis of the organic cotton industry: The case of UK retailers and Indian suppliers. *Ecological Economics*, *69*(11), 2292–2302.

Righi, E., Dogliotti, S., Stefanini, F. M., & Pacini, G. C. (2011). Capturing farm diversity at regional level to up-scale farm level impact assessment of sustainable development options. *Agriculture, Ecosystems & Environment*, *142*(1-2), 63–74.

Rusinamhodzi, L., & Corbeels, M. (2012). Maize–grain legume intercropping is an attractive option for ecological intensification that reduces climatic risk for smallholder farmers in central Mozambique. *Field Crops Research*, *136*, 12–22.

Sakané, N., Becker, M., Langensiepen, M., & Wijk, M. T. (2012). Typology of Smallholder Production Systems in Small East-African Wetlands. *Wetlands*, *33*(1), 101–116.

Sanginga, N. (2003). Role of biological nitrogen fixation in legume based cropping systems; a case study of West Africa farming systems. *Plant and Soil*, *252*(1), 25–39.

Sanogo, O. M., Ridder, N. de, & Keulen, H. van. (2010). Diversité et dynamique des exploitations agricoles mixtes agriculture-élevage au sud du Mali. *Cahiers Agricultures*, *19*(3), 185–193.

Saxena, R. C., & Kidiavai, E. L. (1997). Neem seed extract spray applications as low-cost inputs for management of the flower thrips in the cowpea crop. *Phytoparasitica*, *25*(2), 99–110.

Serra, R. (2012). *Cotton Sector Reforms in Mali: Explaining the Puzzles* (No. Working paper 20) (pp. 1–30). London.

Smith, L., & Subandoro, A. (2007). *Measuring food security using household expenditure surveys* (pp. 65–137). Washington,D.C.: International Food Policy Research Institute.

Sneyd, A. (2015). The poverty of “poverty reduction”: the case of African cotton. *Third World Quarterly*, *36*(1), 55–74.

Sterk, B., & Ittersum, M. Van. (2007). Prototyping and farm system modelling—Partners on the road towards more sustainable farm systems?. *European Journal of Agronomy*, *26*(4), 401–409.

Sundberg, S. (1988). *An Overview of the Food Consumption and Nutrition Situation in Mali*. *Report submited to USAID/Mali/Agricultural Development Office* (pp. 1–66). Bamako.

Tanzubil, P. B. (2008). Control of some insect pests of cowpea (Vigna unguiculuta) with neem (Azadirachta indica A Juss.) in Northern Ghana. *Tropical Pest Management*, *37*(3), 216–217.

TAP for Cotton. (2012). TAP Countries - Country Profile - Mali. Retrieved November 30, 2014, from http://www.cottontapafrica.org/mali.html

Tappan, G., & McGahuey, M. (2007). Tracking environmental dynamics and agricultural intensification in southern Mali. *Agricultural Systems*, *94*(1), 38–51.

Tavernier, E. M., & Tolomeo, V. (2004). Farm Typology and Sustainable Agriculture: Does Size Matter? *Journal of Sustainable Agriculture*, *24*(2), 33–46.

Tefera, H. (2011). Breeding for Promiscuous Soybeans at IITA. In A. Sudaric (Ed.), *Soybean - Molecular Aspects of Breeding* (pp. 147–164). InTech.

Theriault, V., & Tschirley, D. L. (2014). How Institutions Mediate the Impact of Cash Cropping on Food Crop Intensification: An Application to Cotton in Sub-Saharan Africa. *World Development*, *64*, 298–310.

Timler, C., Michalscheck, M., Klapwijk, C., Mashingaidze, N., Ollenburger, M., Falconnier, G., … Groot, J. (2014). *Characterization of farming systems in Africa RISING intervention sites in Malawi, Tanzania, Ghana and Mali* (pp. 86–109). Bamako: International Institute of Tropical Agriculture.

Tittonell, P., & Giller, K. E. (2013). When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. *Field Crops Research*, *143*, 76–90.

Tittonell, P., Muriuki, A., Shepherd, K. D., Mugendi, D., Kaizzi, K. C., Okeyo, J., … Vanlauwe, B. (2010). The diversity of rural livelihoods and their influence on soil fertility in agricultural systems of East Africa – A typology of smallholder farms. *Agricultural Systems*, *103*(2), 83–97.

Tittonell, P., Vanlauwe, B., Leffelaar, P. A., Rowe, E. C., & Giller, K. E. (2005). Exploring diversity in soil fertility management of smallholder farms in western Kenya: I. Heterogeneity at region and farm scale. *Agriculture, Ecosystems & Environment*, *110*(3), 149–165.

Tittonell, P., Vanlauwe, B., Leffelaar, P. A., Shepherd, K. D., & Giller, K. E. (2005). Exploring diversity in soil fertility management of smallholder farms in western Kenya: II. Within-farm variability in resource allocation, nutrient flows and soil fertility status. *Agriculture, Ecosystems & Environment*, *110*(4), 166–184.

Traore, A., & Bickersteth, S. (2011). Addressing the challenges of agricultural service provision: the case of Oxfam's Strategic Cotton Programme in Mali. *International Journal of Agricultural Sustainability*, *9*(1), 82–90.

Turner, M. D., Ayantunde, A. a, Patterson, K. P., & Patterson III, E. D. (2011). Livelihood transitions and the changing nature of farmer-herder conflict in Sahelian West Africa. *The Journal of Development Studies*, *47*(2), 183–206.

Turner, M. D., McPeak, J. G., & Ayantunde, A. (2014). The Role of Livestock Mobility in the Livelihood Strategies of Rural Peoples in Semi-Arid West Africa. *Human Ecology*, *42*(2), 231–247.

UN. (2013). World Population Prospects: The 2012 Revision, DVD Edition. *United Nations Publication*. New York: United Nations, Department of Economic and Social Affairs, Population Division. Retrieved from http://esa.un.org/wpp/Excel-Data/population.htm

Vanlauwe, B., Wendt, J., Giller, K. E., Corbeels, M., Gerard, B., & Nolte, C. (2014). A fourth principle is required to define Conservation Agriculture in sub-Saharan Africa: The appropriate use of fertilizer to enhance crop productivity. *Field Crops Research*, *155*, 10–13.

Vereijken, P. (1997). A methodical way of prototyping integrated and ecological arable farming systems (I/EAFS) in interaction with pilot farms. *Developments in Crop Science*, *25*, 293–308.

Vlek, P. L. G. (1990). The role of fertilizers in sustaining agriculture in sub-Saharan Africa. *Fertilizer Research*, *26*(1), 327–339.

Waddington, S. R., Mekuria, M., Siziba, S., & Karigwindi, J. (2007). Long-term yield sustainability and financial returns from grain legume-maize intercrops on a sandy soil in subhumid North Central Zimbabwe. *Experimental Agriculture*, *43*(04), 489–503.

Wahua, T. A. T., & Miller, D. A. (1978). Effects of Intercropping on Soybean N2-Fixation and Plant Composition on Associated Sorghum and Soybeans. *Agronomy Journal*, *70*(2), 292.

Willey, R. W. (1979). Intercropping: Its Importance and Research Needs. Part 1, Competition and Yield Advantages. *Field Crop Abstracts*, *32*(1), 1–20.

Wilson, R. (1986). Livestock production systems. In R. T. Wilson, P. N. de Leeuw, & C. de Haan (Eds.), *Livestock Production in Central Mali: Long-term Studies on Cattle and Small Ruminants in the Agropastoral System* (pp. 9–19). Addis Ababa: International Livestock Research Institute (ILRI).

WorldAtlas. (n.d.). Map of Mali. Retrieved November 30, 2014, from http://www.worldatlas.com/webimage/countrys/africa/ml.htm

Zingore, S., Murwira, H. K., Delve, R. J., & Giller, K. E. (2007). Influence of nutrient management strategies on variability of soil fertility, crop yields and nutrient balances on smallholder farms in Zimbabwe. *Agriculture, Ecosystems & Environment*, *119*(1-2), 112–126.

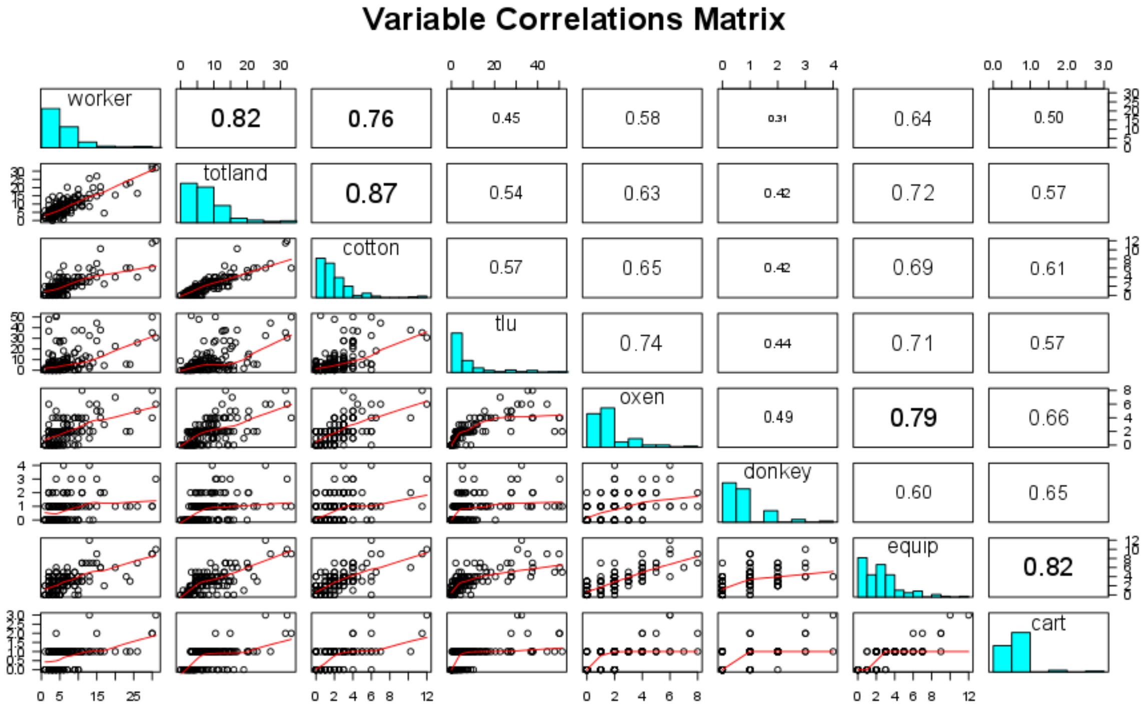
Zorom, M., Barbier, B., Mertz, O., & Servat, E. (2013). Diversification and adaptation strategies to climate variability: A farm typology for the Sahel. *Agricultural Systems*, *116*, 7–15.

Annex 1. R script for the farm typology

```
library(ade4)                     # for principal components analysis
library(car)                      # for recoding the farm types

mali=read.csv(file.choose(),header=T,sep=",")
x=is.na(mali)                     # find missing values
summary(x)

###1. Data verification in R

summary(mali)

## potential outliers

boxplot(mali$worker)
boxplot(mali$totland)
boxplot(mali$cotton)
boxplot(mali$tlu)                 # 21,73 (>70 TLU)
boxplot(mali$oxen)
boxplot(mali$equip)
boxplot(mali$cart)
mali= mali[-c(21,73),]            # Exclude the outliers

## create panel.cor function
panel.cor <- function(x, y, digits = 2, prefix = "", cex.cor, ...){
  usr <- par("usr"); on.exit(par(usr))
  par(usr = c(0, 1, 0, 1))
  r <- abs(cor(x, y))
  txt <- format(c(r, 0.123456789), digits = digits)[1]
  txt <- paste0(prefix, txt)
  if(missing(cex.cor)) cex.cor <- 0.8/strwidth(txt)
  text(0.5, 0.5, txt, cex = cex.cor * r)
}
 ## create panel.hist function
panel.hist <- function(x, ...){
  usr <- par("usr"); on.exit(par(usr))
  par(usr = c(usr[1:2], 0, 1.5) )
  h <- hist(x, plot = FALSE)
  breaks <- h$breaks; nB <- length(breaks)
  y <- h$counts; y <- y/max(y)
  rect(breaks[-nB], 0, breaks[-1], y, col = "cyan", ...)
}

## pairs() function creates a scatterplot matrix
pairs(mali[,-c(1,2)], upper.panel = panel.cor, diag.panel = panel.hist,
      lower.panel = panel.smooth, main="Variable Correlations Matrix",
      cex.lab=2,cex.axis=0.75,las=1)

###2. Pincipal Component Analysis

datam=mali[,-c(8)]                # exlude the donkey variables

mali.pca = dudi.pca(datam[,-c(1,2)], scannf=T, nf=8)
2                                 # 2 components explain all data (82.98%)
summary(mali.pca)                 # Eigenvalues 4.97(70.96%),0.84(12.02%)
names(mali.pca)

barplot(mali.pca$eig,col=gray.colors(8),ylim=c(0,5),ylab="Eigenvalues",
       main="Principal Components Barplot",beside=T, legend.text=T,las=1)
```

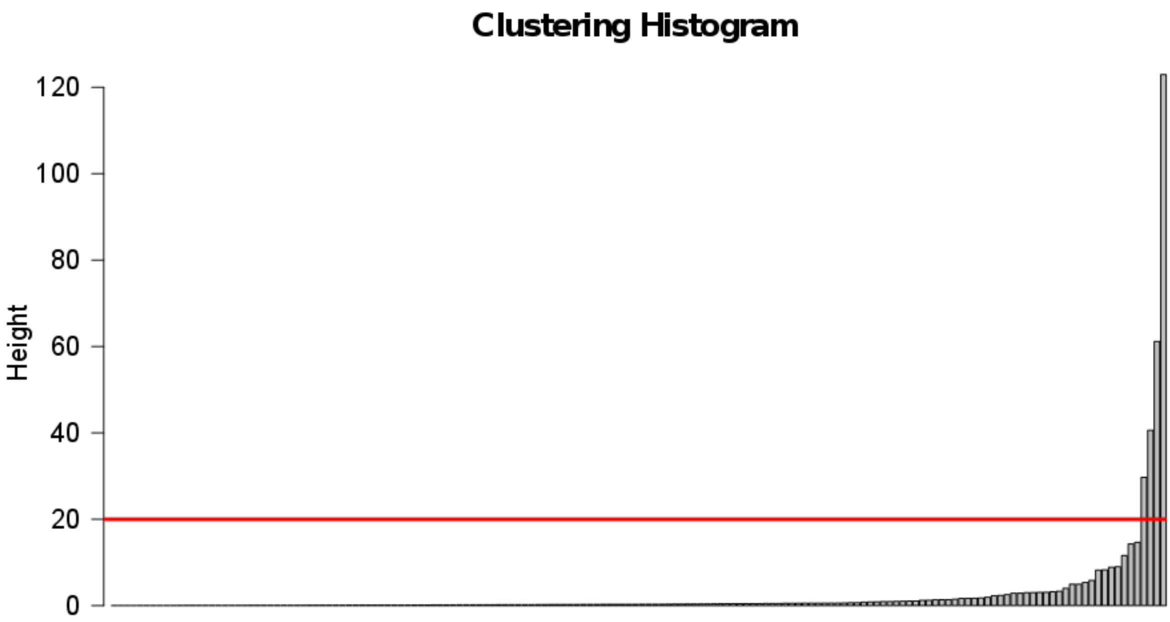
```
par(mfrow=c(1,2))

## the scatter diagram of a correlation circle

par(mfrow=c(1,1))
scatter.dudi(mali.pca,xax=1,yax=2,clab.row = 0, clab.col = 1,
             posieig = "topright",sub="PC1-PC2",col=2)

###3. Hierarchical Clustering analysis

mali.hc = hclust(dist(mali.pca$li), method="ward.D")
par(mfrow=c(1,1))
barplot(mali.hc$height,width=1,xlim=c(6,187),ylab="Height",
        main="Clustering Histogram",las=1)
abline(h=20,col="red",lwd=3)
plot(mali.hc, cex=0.5,las=1)
box()
abline(h=20,col=2,lwd=3)

###4. Final results by five farm types
typo = cutree(mali.hc, k=5)
datam$typo=typo
datam$typo=as.factor(datam$typo)

datam$typo <- recode(datam$typo,"5=1;2=2;3=3;1=4;4=5")

par(mfrow=c(1,1))
s.class(mali.pca$li, fac=as.factor(datam$typo),
        col=levels(datam$typo),xax=1, yax=2,sub="PC1-PC2")
s.class(mali.pca$li, fac=datam$village,
        col=levels(datam$village1) ,xax=1, yax=2,sub="PC1-PC2")

par(mfrow=c(2,4))
boxplot(datam$worker ~ datam$typo, main="Worker",las=1)
boxplot(datam$totland ~ datam$typo, main="Total_land",las=1)
boxplot(datam$cotton ~ datam$typo, main="Cotton_land",las=1)
boxplot(datam$tlu ~ datam$typo,main="Herd_size(TLU)",las=1)
boxplot(datam$oxen ~ datam$typo,main="Oxen",las=1)
boxplot(datam$equip ~ datam$typo, main="Tools",las=1)
boxplot(datam$cart ~ datam$typo, main="Cart",las=1)

datam.long <-melt(datam,id.vars=c('num','village','typo'))
type.means<-cast(datam.long,typo~variable,fun.aggregate=mean)
```

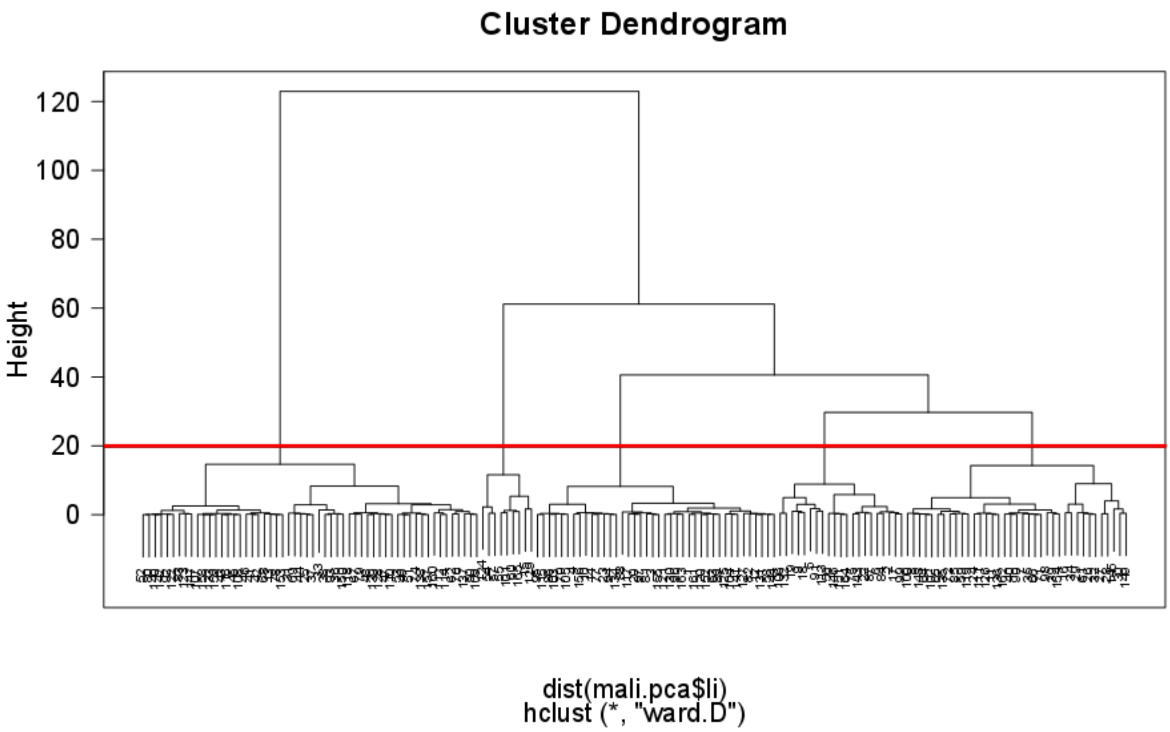
Annex 2. Variable correlation matrix in R for data pre-check



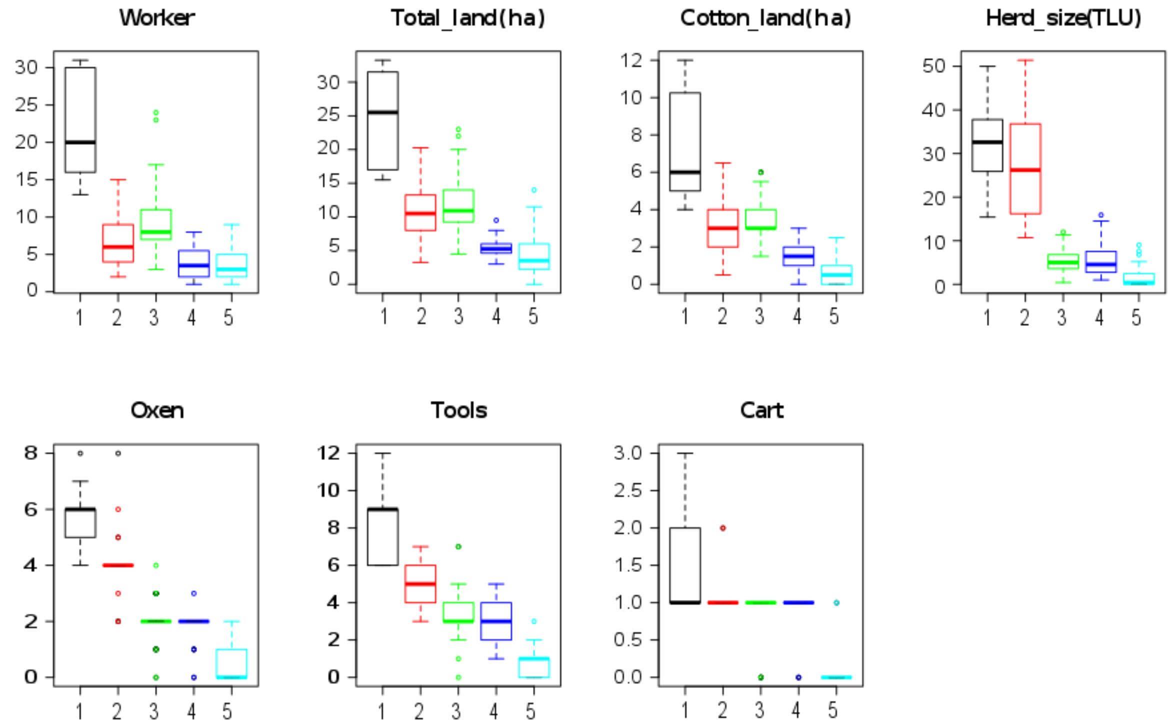
Note: worker (the number of workers), totland (total crop area (ha)), cotton (cotton area (ha)), tlu (herd size (TLUs)), oxen (heads of oxen), donkey (heads of donkey), equip (the number of equipment), cart (the number of carts)

Annex 3. Clustering histogram and dendrogram with a red break line





Annex 4. Boxplots of seven variables by five farm types



Annex 5. The number of households by five farm types in four villages

	Farm types				
	1	2	3	4	5
Dieba	1	8	15	8	20
Ratio	*2%*	*15%*	*29%*	*15%*	*38%*
Flola	4	2	7	3	6
Ratio	*18%*	*9%*	*32%*	*14%*	*27%*
Madina	1	6	7	17	16
Ratio	*2%*	*13%*	*15%*	*36%*	*34%*
Sibirila	3	5	8	12	14
Ratio	*7%*	*12%*	*19%*	*29%*	*33%*
Total	9	21	37	40	56
Ratio	*6%*	*13%*	*23%*	*25%*	*34%*

Annex 6. Survey questionnaire of organic cotton farmers in three villages

Farmer name:____________ Village___________

1. Resource endowment

Worker	Cotton (ha)	Maize (ha)	Sorghum (ha)	Millet (ha)	Cowpea (ha)	Rice (ha)
	Ridger	Weeder	Multi-cultivator	Seeder	Plow TM	Cart
	Oxen	Cattle	Donkey	Goat		

2. Cotton input

Input	Cotton type	Type	Quantity	Unit (kg/bag/L)	Period	Origin	Price(Fcfa/unit)
Seeds	Organic	Non-treated					
	Conventional	Treated/non-					
Pesticide	Organic	Neem					
		Koby oil					
	Conventional	Nomax 150 SC					
		Fanga 500 EC					
Herbicide	Conventional	Glycel					
		Super Glue					
Fertilizer	Organic	Manure					
		Compost					
	Conventional	Urea					
		NPK complex					

3. Labor calendar

Cotton	Activity	Month	Labor	Days	Origin	Cost	Oxen	Origin	Cost	Donkey	Origin	Cost
Org	Prepare land											
	Plough											
	Sowing											
	1st weeding											
	Apply compost											
	2nd weeding											
	Ridging											
	Spray insecticide											
	Harvest											
	Transport											

Con	Land preparation											
	Plough											
	Sowing											
	Spray herbicides											
	1st weeding											
	Apply Complex											
	2nd weeding											
	Apply urea											
	Ridging											
	Insecticide											
	Harvest											
	Transport											

4. The cost and life expectancy of animal and equipment

Donkey		Oxen		Cart		Ridger	
Price (Fcfa)	Life (year)	Price (Fcfa)	Life (year)	Price (Fcfa)	Life (year)	Price (Fcfa)	Life (year)
Multi-cultivators		Weeder		Plow TM		Sprayer	
Price (Fcfa)	Life (year)	Price (Fcfa)	Life (year)	Price (Fcfa)	Life (year)	Price (Fcfa)	Life (year)

5. Crop outputs

Crop output	Quantity	Unit (kg or bag)
Seed cotton (org)		
Seed cotton (con)		
Maize		
Peanut		
Rice		
Sorghum		
Millet		

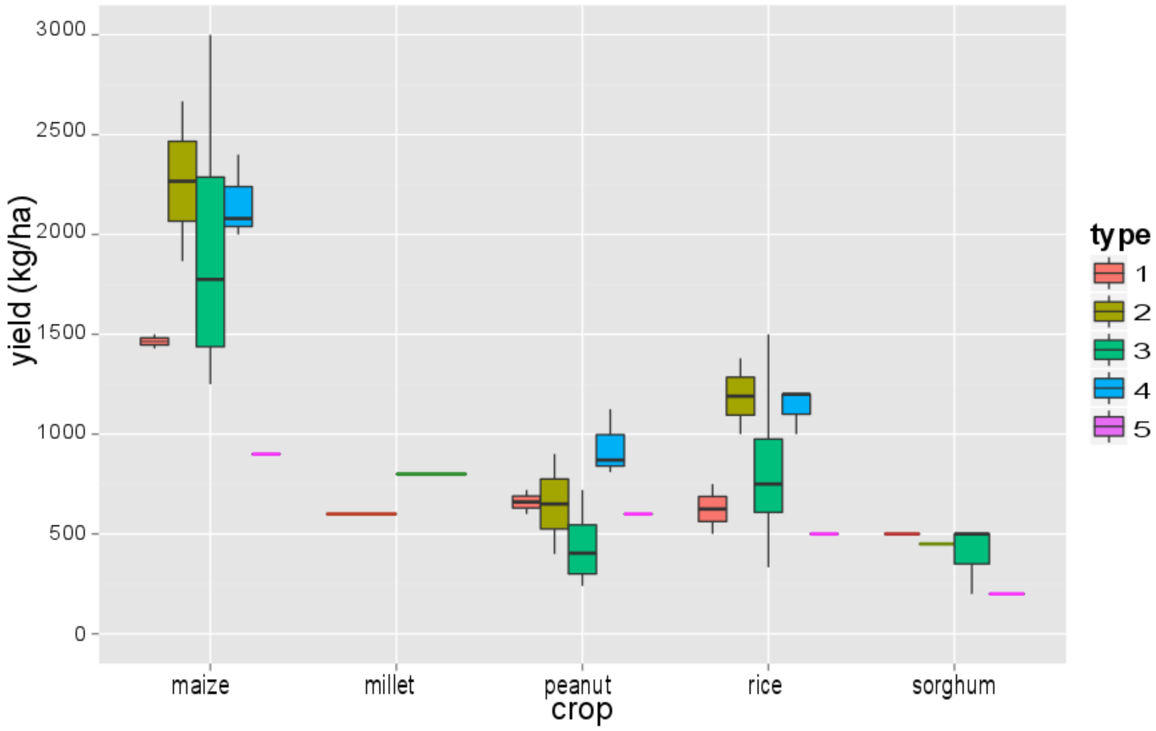
6. Questions

1) Did you participate in the cotton trainings from CMDT before, and did these trainings help you improve the cotton management skills and what else did you acquired?

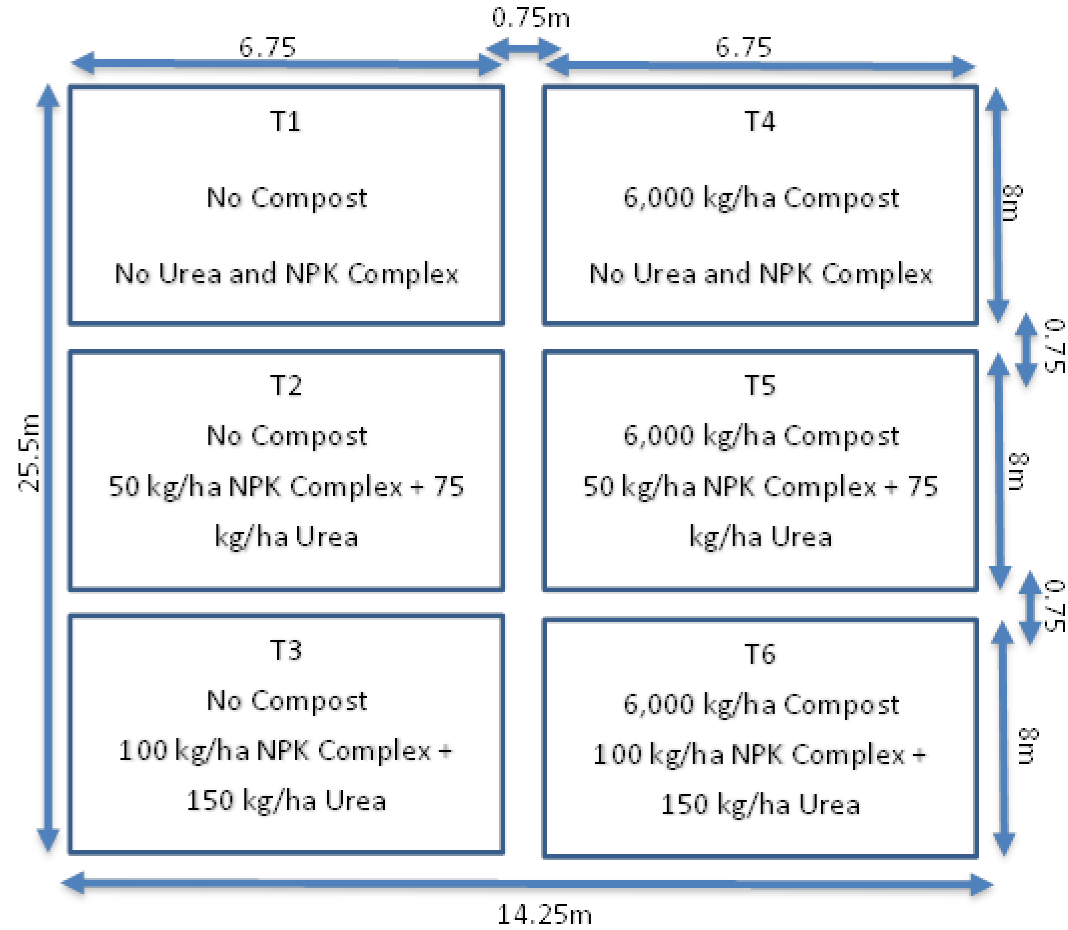
2) Do you take the organic cotton trainings from Mobiom, and did these courses help you improve your organic cotton management skills and what else did you acquired?

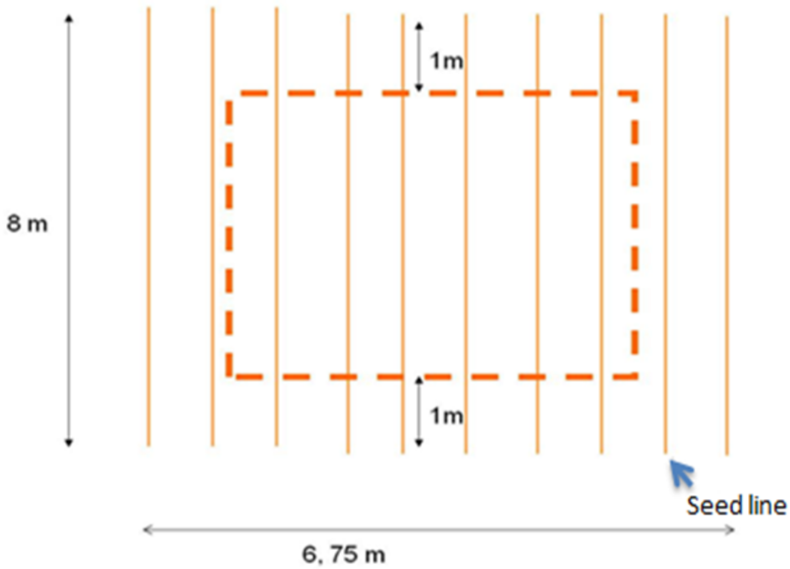
3) What was your main challenge for cultivating organic cotton?

Annex 7. Farmer reported crop yields from the interview

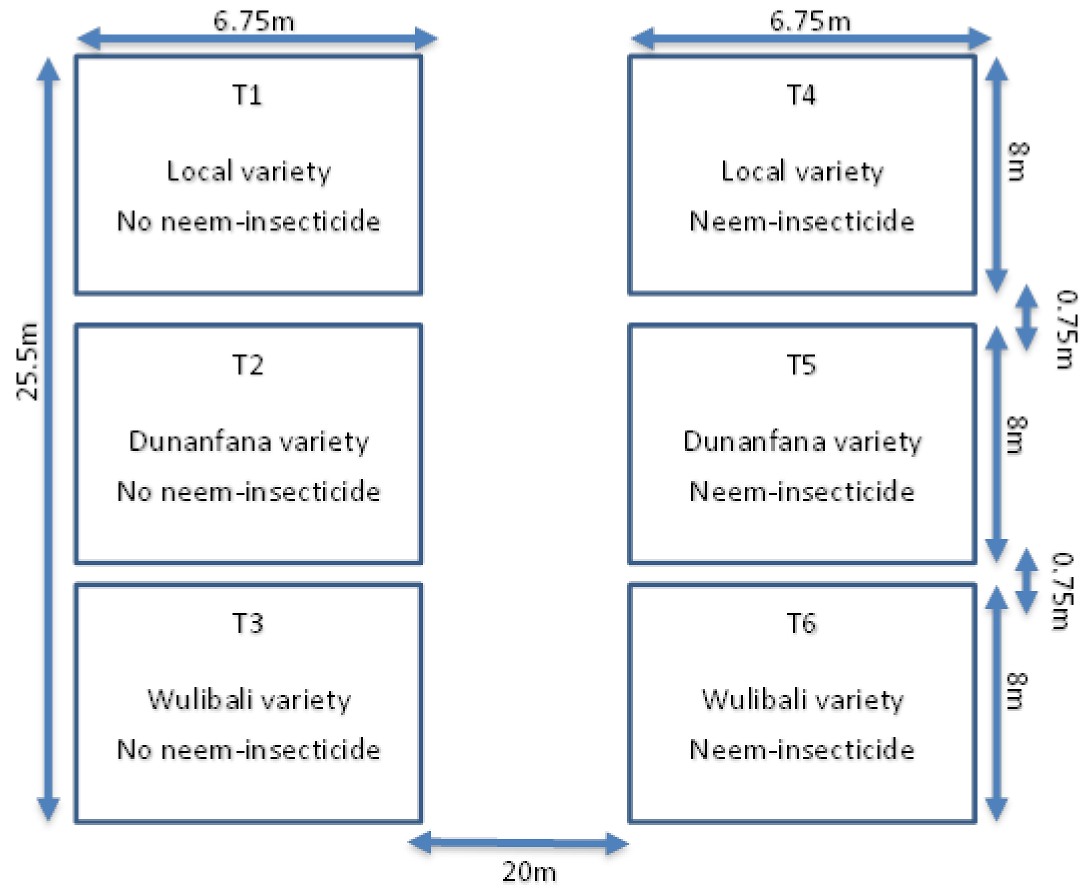


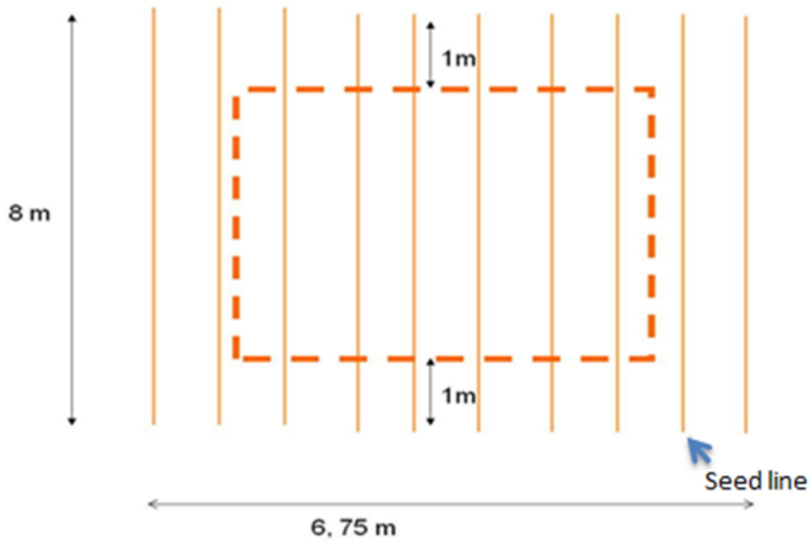
Annex 8. Maize trials experiment design and harvest protocol



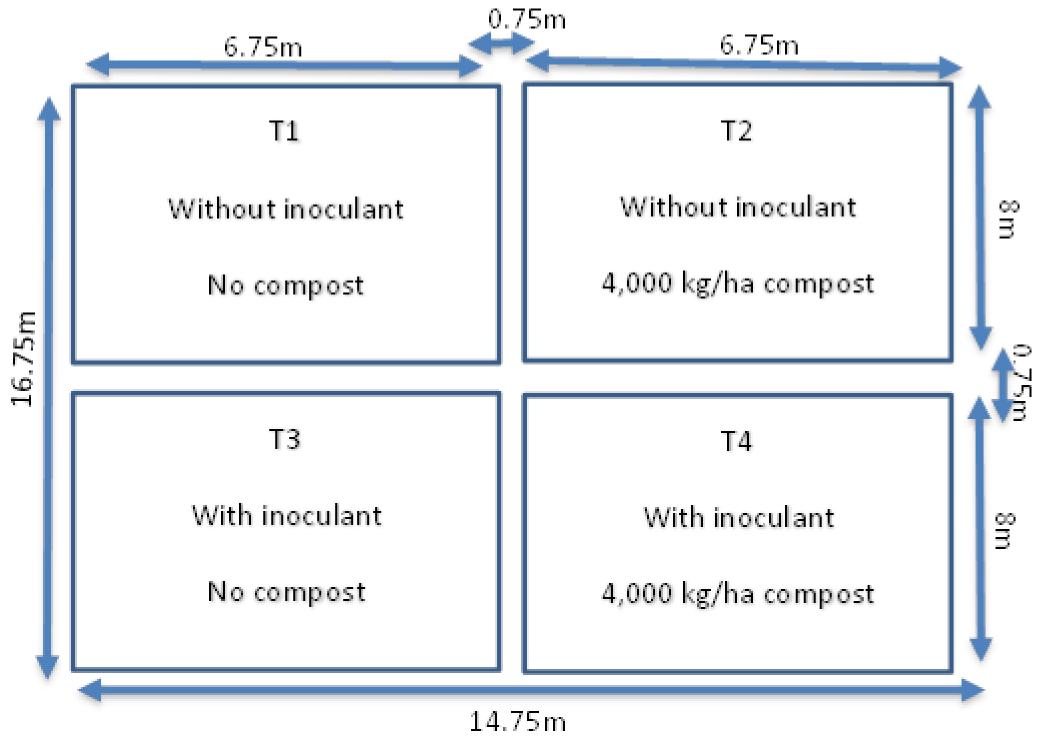


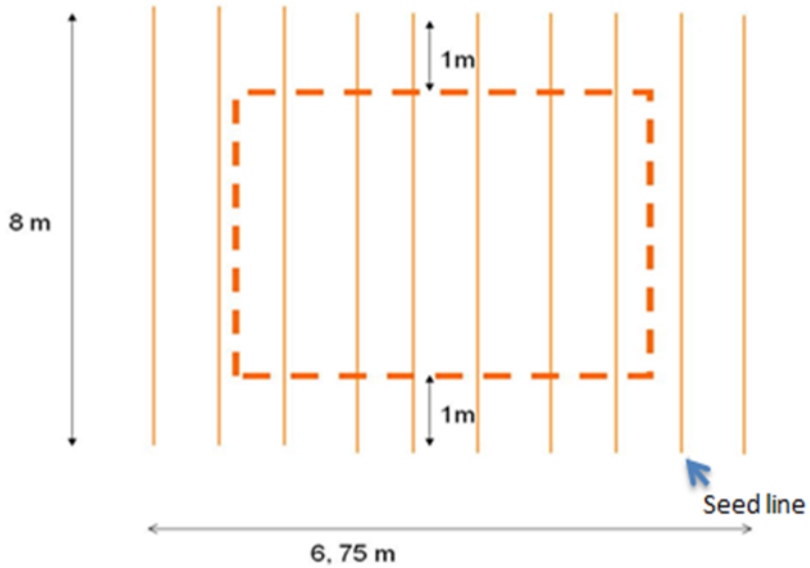
Annex 9. Cowpea trials experiment design and harvest protocol



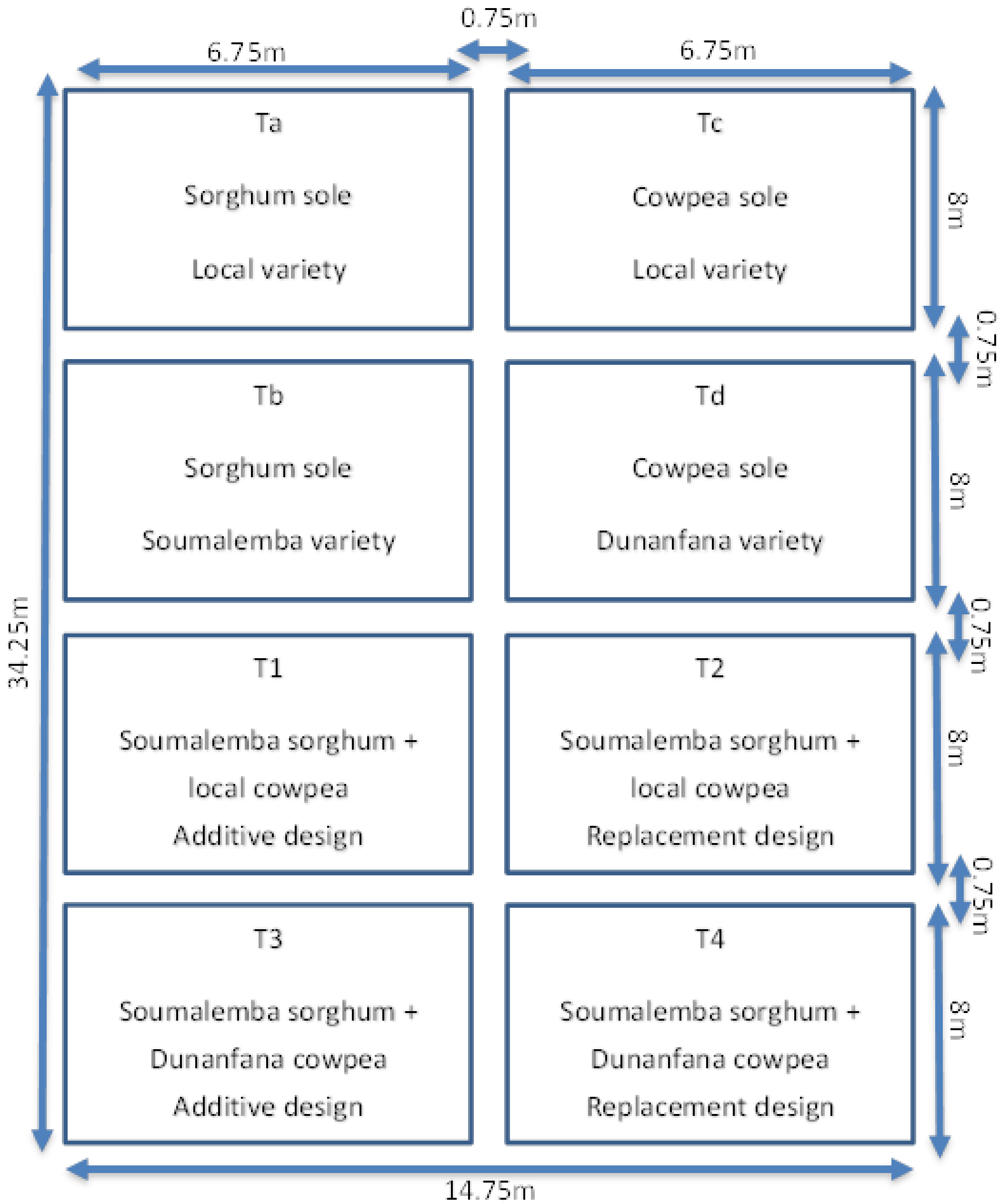


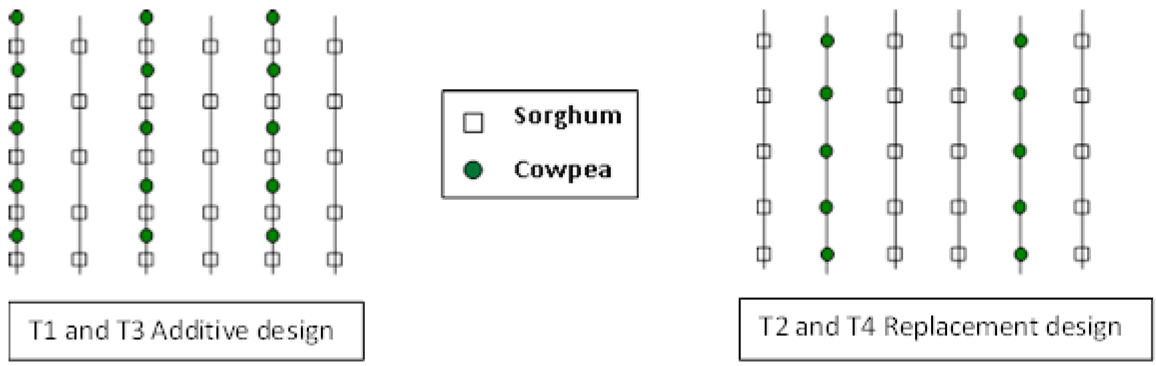
Annex 10. Soybean trials experiment design and harvest protocol

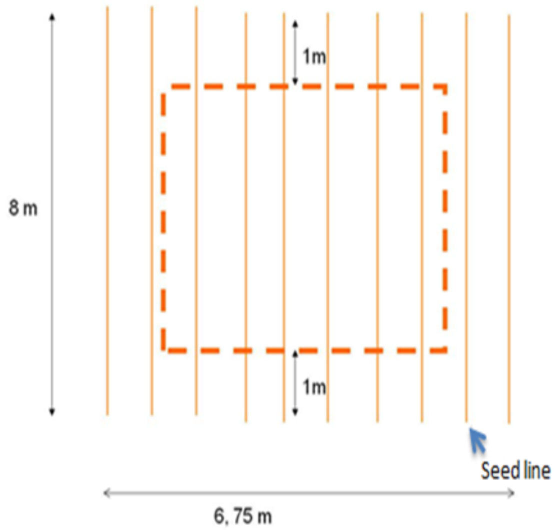




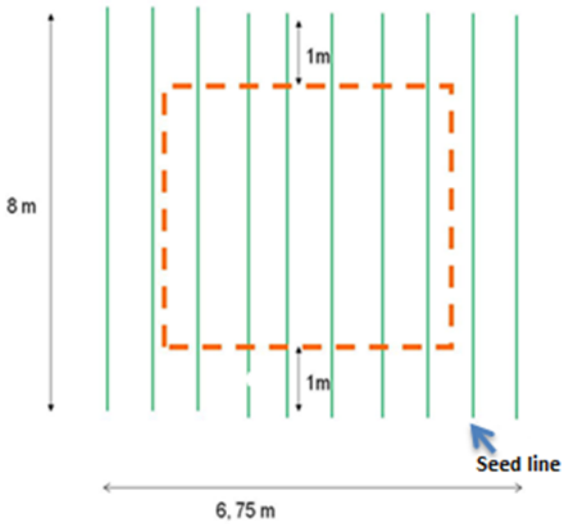
Annex 11. Sorghum-cowpea trials experiment design and harvest protocol



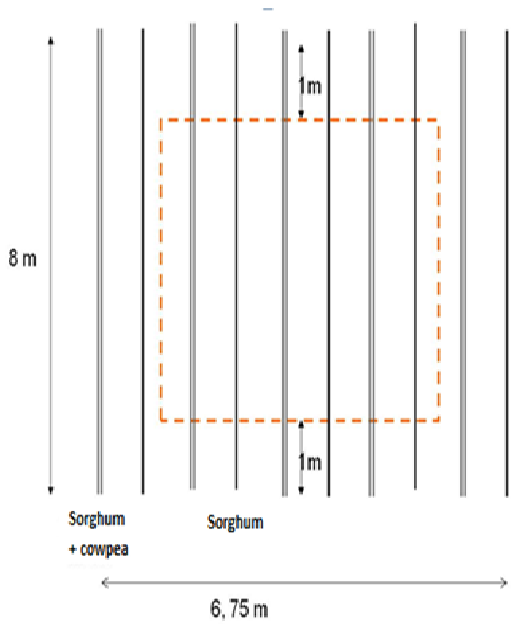




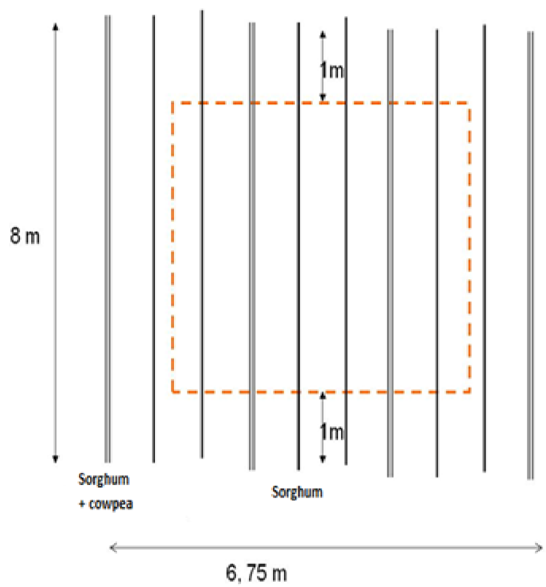
Ta and Tb Sorghum solo



Tc and Td Cowpea solo



T1 and T3 Additive design



T2 and T4 Replacement design

Annex 12. R script for the maize trials

```
library(ggplot2)
library(plyr)
library(pgirmess)
library(car)

maize=read.csv(file.choose(),header=T,sep=",")

maize$compost=as.factor(maize$compost)
maize$fertilizer=factor(maize$fertilizer,levels=c("0","half","full"))

yield_g=maize[,-c(1,2,5)]      # create data_frame of the treatment-grain
yield_s=maize[,-c(1,2,6)]      # create data_frame of the treatment-stover

### normality test

shapiro.test(yield_g$grain)           # W = 0.66947, p-value = 2.94e-13
shapiro.test(yield_s$stover)          # W = 0.8718, p-value = 6.58e-08

### homogeneity test

leveneTest(yield_g$grain ~ yield_g$compost)    # p= 0.62
leveneTest(yield_g$grain ~ yield_g$fertilizer) # p= 0.26
leveneTest(yield_s$stover ~ yield_s$compost)    # p= 0.93
leveneTest(yield_s$stover ~ yield_s$fertilizer) # p= 0.52

### summary for grain and stover yield

sum_g  =  summarySE(yield_g,  measurevar  =  "grain",  groupvars  =  c("compost"
,"fertilizer"))
sum_s  =  summarySE(yield_s,  measurevar="stover",  groupvars  =  c("compost"
,"fertilizer"))

### barplot

ggplot(sum_g, aes(x=fertilizer, y=grain, fill=compost)) +
  geom_bar(position=position_dodge(), stat="identity",
           colour="black", # Use black outlines,
           size=.3) +      # Thinner lines
  geom_errorbar(aes(ymin=grain-se, ymax=grain+se),
                size=.3,    # Thinner lines
                width=.2,
                position=position_dodge(.9)) +
  xlab("Fertilizer dose") +
  ylab("Grain yield (kg/ha)") +
  scale_fill_hue(name="Compost",
                 breaks=c("0", "6000"),
                 labels=c("no compost","with compost")) +
  theme(text=element_text(size=18))

ggplot(sum_s, aes(x=fertilizer, y=stover, fill=compost)) +
  geom_bar(position=position_dodge(), stat="identity",
```

```
          colour="black",
          size=.3) +
  geom_errorbar(aes(ymin=stover-se, ymax=stover+se),
               size=.3,
               width=.2,
               position=position_dodge(.9)) +
  xlab("Fertilizer dose") +
  ylab("Stover yield (kg/ha)") +
  scale_fill_hue(name="Compost",
                breaks=c("0","6000"),
                labels=c("no compost","with compost")) +
  theme(text=element_text(size=18))

### kruskal wallis test and multiple comparison

kruskal.test(grain ~ compost, data= yield_g)        # p= 0.099
kruskal.test(grain ~ fertilizer, data= yield_g)     # p= 0.02
kruskalmc(grain ~ compost, data=yield_g, probs = 0.05)    # no sig
kruskalmc(grain ~ fertilizer, data=yield_g, probs = 0.05) # significant
difference 0-full dose
kruskal.test(stover~ compost, data= yield_s)              # p=0.70
kruskal.test(stover ~ fertilizer, data= yield_s)          # p=0.11
kruskalmc(stover ~ compost, data=yield_s, probs = 0.05)    # no sig
kruskalmc(stover ~ fertilizer, data=yield_s, probs = 0.05) # no sig
```

Annex 13. R script for the cowpea trials

```
library(ggplot2)
library(plyr)
library(pgirmess)
library(car)

cowpea=read.csv(file.choose(),header=T,sep=",")
yield_g=cowpea[,-c(1,2,5)]       # create data frame of the treatment-grain
yield_h=cowpea[,-c(1,2,6)]       # create data frame of the treatment-haulm

### normality test

shapiro.test(yield_g$grain)           # W = 0.6156, p-value = 7.67e-16
shapiro.test(yield_h$haulm)           # W = 0.8813, p-value = 4.741e-08

### homogeneity test

leveneTest(yield_g$grain ~ yield_g$neem)    # p=0.1364
leveneTest(yield_g$grain ~ yield_g$variety) # p= 1.892e-08 ***
leveneTest(yield_h$haulm ~ yield_h$neem)    # p=0.6011
leveneTest(yield_h$haulm ~ yield_h$variety) # p=0.002 **

### summary for grain and haulm yield

sum_g = summarySE(yield_g, measurevar="grain",
groupvars=c("variety","neem"))
sum_h = summarySE(yield_h, measurevar="haulm",
groupvars=c("variety","neem"))

### barplot

ggplot(sum_g, aes(x=variety, y=grain, fill=neem)) +
        geom_bar(position=position_dodge(), stat="identity",
           colour="black", # Use black outlines,
           size=.3) +      # Thinner lines
        geom_errorbar(aes(ymin=grain-se, ymax=grain+se),
                size=.3,    # Thinner lines
                width=.2,
                position=position_dodge(.9)) +
        xlab("Variety") +
        ylab("Grain yield (kg/ha)") +
        scale_fill_hue(name="Neem",                # Legend label, use
darker colors
                 breaks=c("no", "yes"),
                 labels=c("No neem","With neem")) +
        theme(text=element_text(size=18))

ggplot(sum_h, aes(x=variety, y=haulm, fill=neem)) +
       geom_bar(position=position_dodge(), stat="identity",
           colour="black", # Use black outlines,
           size=.3) +      # Thinner lines
      geom_errorbar(aes(ymin=haulm-se, ymax=haulm+se),
                size=.3,    # Thinner lines
                width=.2,
                position=position_dodge(.9)) +
  xlab("Variety") +
  ylab("Haulm yield (kg/ha)") +
  scale_fill_hue(name="Neem",                # Legend label, use darker
colors
```

```
                 breaks=c("no","yes"),
                 labels=c("No neem","With neem")) +
  theme(text=element_text(size=18))

### kruskal wallis test and multiple comparison

kruskal.test(grain ~ neem, data= yield_g)        # p= 0.41
kruskal.test(grain ~ variety, data= yield_g)     # p=3.3e-7
kruskalmc(grain ~ neem, data=yield_g, probs = 0.05)    # no sig
kruskalmc(grain ~ variety, data=yield_g, probs = 0.05) # no sig
kruskal.test(haulm ~ neem, data= yield_h)              # p=0.65
kruskal.test(haulm ~ variety, data= yield_h)           # p=6.22e-10
kruskalmc(haulm ~ neem, data=yield_h, probs = 0.05)    # no sig
kruskalmc(haulm ~ variety, data=yield_h, probs = 0.05) # significant
difference dunanfana-local and dunanfana-wulibali
```

Annex 14. R script for the soybean trials

```
library(ggplot2)
library(plyr)
library(pgirmess)
library(car)

soya=read.csv(file.choose(),header=T,sep=",")
soya$compost= as.factor(soya$compost)
names(soya)
yield_g=soya[,-c(1,2,6)]       # create data frame of treatment-grain
yield_h=soya[,-c(1,2,5)]       # create data frame of treatment-haulm

### normality

shapiro.test(yield_g$grain)           # W = 0.6156, p-value = 0.019
shapiro.test(yield_h$haulm)           # W = 0.8813, p-value = 0.007

### homogeneity test

leveneTest(yield_g$grain ~ yield_g$inoculant)    # p=0.8
leveneTest(yield_g$grain ~ yield_g$compost)     # p=0.4
leveneTest(yield_h$haulm ~ yield_h$inoculant)    # p=0.76
leveneTest(yield_h$haulm ~ yield_h$compost)     # p=0.25

### summary for grain and haulm yield

sum_g = summarySE(yield_g, measurevar="grain",
groupvars=c("compost","inoculant"))
sum_h = summarySE(yield_h, measurevar="haulm",
groupvars=c("compost","inoculant"))

### barplot

ggplot(sum_g, aes(x=compost, y=grain, fill=inoculant)) +
  geom_bar(position=position_dodge(), stat="identity",
           colour="black", # Use black outlines,
           size=.3) +      # Thinner lines
  geom_errorbar(aes(ymin=grain-se, ymax=grain+se),
                size=.3,     # Thinner lines
                width=.2,
                position=position_dodge(.9)) +
  xlab("Compost (kg/ha)") +
  ylab("Grain yield (kg/ha)") +
  scale_fill_hue(name="Inoculant",         # Legend label, use darker colors
                 breaks=c("no","yes"),
                 labels=c("non-inoculated","inoculated")) +
  theme(text=element_text(size=18))

ggplot(sum_h, aes(x=compost, y=haulm, fill=inoculant)) +
  geom_bar(position=position_dodge(), stat="identity",
           colour="black", # Use black outlines,
           size=.3) +      # Thinner lines
  geom_errorbar(aes(ymin=haulm-se, ymax=haulm+se),
                size=.3,     # Thinner lines
                width=.2,
                position=position_dodge(.9)) +
  xlab("Compost (kg/ha)") +
  ylab("Haulm yield (kg/ha)") +
```

```
  scale_fill_hue(name="Inoculant",                  # Legend label, use
darker colors
                 breaks=c("no","yes"),
                 labels=c("non-inoculated","inoculated")) +
  theme(text=element_text(size=18))

### kruskal wallis test and mulitiple comparison

kruskal.test(grain ~ compost, data= yield_g)                # p=0.2
kruskal.test(grain ~ inoculant, data= yield_g)              # p=0.9
kruskalmc(grain ~ inoculant, data=yield_g, probs = 0.05)    # no sig
kruskalmc(grain ~ compost, data=yield_g, probs = 0.05)      # no sig
kruskal.test(haulm ~ compost, data= yield_h)                # p=0.16
kruskal.test(haulm ~ inoculant, data= yield_h)              # p=0.5
kruskalmc(haulm ~ compost, data=yield_h, probs = 0.05)      # no sig
kruskalmc(haulm ~ inoculant, data=yield_h, probs = 0.05)    # no sig
```