# INCOME, CROP DIVERSIFICATION STRATEGIES AND AGRICULTURAL PRACTICES IN CROP AND LIVESTOCK PRODUCTION SYSTEMS IN SOUTHERN MALI

**BANDIOUGOU DEMBELE**

**A Thesis Submitted to the Graduate School in Partial Fulfilment for the Requirements of the Award of PhD Degree in Agricultural Economics of Egerton University**

**EGERTON UNIVERSITY**

**October, 2018**

## DECLARATION AND RECOMMENDATION

**Declaration**

This research thesis is wholly my original work and has not been submitted for an award of any degree in any other University.

___________ _______________

Signature Date

Bandiougou Dembele

KD15/00379/15

**Recommendation**

This thesis has been submitted with our approval as the University Supervisors.

____________________ ____________________

Signature Date

Dr. Hillary K. Bett, PhD.

Senior lecturer, Department of Agricultural Economics and Agribusiness Management,

Egerton University, Kenya

_________________ _____________________

Signature Date

Dr. Isaac Maina Kariuki, PhD.

Senior lecturer, Department of Agricultural Economics and Agribusiness Management,

Egerton University, Kenya

## DEDICATION

I dedicate this PhD thesis to my late Dad Abdoulaye DEMBELE for this hard work and sincere support. May his soul rest in peace forever.

# ACKNOWLEDGEMENT

I would like to thank Almighty God for seeing me throughout the course of my entire study. I thank Egerton University for giving me the opportunity to pursue my PhD degree in Kenya. Special thanks also go to my supervisors Dr. Hillary K Bett and Dr. Isaac Maina Kariuki for their tireless supervision, guidance and support throughout my study period. I also thank Dr. Marjorie Le Bars for her guidance. The late Dr. Mary Maina Mutai who her input has been invaluable from the process of proposal writing to thesis writing. I would like to acknowledge United States Agency for International Development (USAID) through Borlaug Higher Education for Agricultural Research and Development (BHEARD) coordination for the scholarship, including the research fund and school fees, they offered me to pursue my PhD degree in Agricultural Economics at Egerton University. I wish to thank the Department of Agricultural Economics and Agribusiness Management for supporting me since I enrolled for my PhD studies. Special thanks go to Dr. Oscar Ingasia for his assistance throughout the work from proposal writing to thesis writing. My sincere thanks also go to my employer Institut d'Economie Rurale (IER). Many thanks towards my colleagues at the Institut d'Economie Rurale (IER) Dr Harouna Yossi, Dr. Odiaba Samake. My gratitude goes to the Lecturers at the department of Agricultural Economics and Agribusiness Management Prof. P. Mshenga, Prof. George Owuor, Prof. J.K. Lagat, Prof B. K Mutai, Prof M.Ngigi, Prof .G. Obare, and Dr. Langat for their support throughout of the study. Acknowledgement also goes to my colleagues from Kenya and Mali for sharing with me useful ideas during my entire period of study and research. I also wish to thank the farmers who accepted to provide information during data collection.

## ABSTRACT

Smallholder farmers in Southern Mali mainly in the cotton production zone are facing decreasing income over time. This constraint makes producers resort to alternative sources of income to supplement agricultural activities to sustain and secure their livelihoods situation. However, the diversified crops and having multiple sources of agricultural income constitute the significant opportunity for smallholder farmers to ensure food security and reduce over dependency on income from cotton. Thus, the main objective of this study was to contribute to the improvement of the livelihood conditions of smallholder farmers through income and crop diversification strategies. The study was conducted in three villages in the cotton-growing zone with different agro-climatic conditions. A multistage sampling technique procedure was used to obtain a sample size of 134 farmers who were selected randomly. A semi-structured questionnaire was used to collect cross-sectional data from smallholder farmers while focus group discussions was used to collect data on agricultural production systems in each village. Descriptive statistics, Principal Component Analysis (PCA), multivariate probit, seemingly unrelated regression, multinomial logit, logit model, bivariate probit, stochastic frontier analysis (SFA) were used for the analysis. Simulation was also done to understand and predict the dynamics of smallholder farmer's income. Findings distinguished 5 types of smallholder farmers. Type 1 was super large families representing 14 % of the total smallholder farmers. Type 2 was large families and constituted 28 % of the smallholder farmers. Type 3 was medium-sized families that represented 28 % of the total smallholder farmers. Type 4 and type 5 were small and young families and represented 19 % and 11 % of smallholder farmers, respectively. Farmers' endowment and institutional factors constitute major determinants of multiple sources of income and crops diversifications strategies. Stochastic frontier model for mean technical efficiencies were 58%, 80% and 84% for maize and millet, sorghum and cotton producers, respectively. Agricultural technology practices were significantly influenced by farmer's characteristics, factors endowment, and institutional factors. Simulation of collective decision for farming revealed different scenarios regarding gross margin across 5 types of smallholder farmers. Policy interventions therefore, should be considered to encourage and promote profit-oriented activities through diversification strategies. In addition, policymakers and agricultural development programs should target strengthening of institutions and enhance farmer's access to productive resources. Future research should be based on agricultural technology adoption by farmers in Southern-Mali for improvement of food security.

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF ABBREVIATIONS ACRONYMS

**AFF**: Agricultural family farming

**BAD**: Banque Africaine pour le Developpement (African Development Bank)

**CFA**: Community Finance for Africa

**CMDT**: Compagnie Malienne pour le Développement des Textile Malian Company of Textile Development

**CCP**: Cooperative of Cotton Producers

**DHI** : Development Human Index

**FAO**: Food and Agricultural Organizations (United Nations)

**AHC**: Ascending Hierarchic Classification

**IAL**: Integration of agriculture and livestock

**IER**: Institut d'Economie Rurale (Institute of Rural Economic)

**INSTAT**: Institute of National Statistic

**GDP**: Gross Domestic Product

**kg**: Kilogram

**KES** Kenya Shilling

**MDG's:** Millennium Development Goals

**MVA**: Multivariate analysis

**MVP** Multivariate probit

**MNL** Multinomial logit

**NGO's** Non-Governmental Organizations

**OECD**: Organization for Economic Cooperation and Development

**PASE2**: Improvement Program for Exploitation Systems in the Cotton Zone

**PCA**: Principal Components Analysis

**RGPH** : General Census of Population and Housing

**SSA**: Sub Saharan Africa

**SFA** Stochastic Frontier Analysis

**SSWA**: Sudano- Sahelian zone in West Africa

**TE**: Technical Efficiency

**TLU**: Tropical livestock Unit

**USAID**: United States Agency for International Development

**WFP**: World Food Program

# CHAPTER ONE

# INTRODUCTION

## 1.1. Background information

Smallholder farmers in Sub-Saharan Africa (SSA) earn their livelihood from different activities such as crop and livestock production, trade, self-employment, among others. According to Makel and Usami (2009) in Bangladesh rural economies in developing countries depend on diverse sources of income. For instance, the agricultural and non-agricultural sectors play an important role in reducing poverty levels. In addition, Schwarze and Zeller (2005) estimated that in Indonesia, households adopted two major strategies to improve their income. In Latin America, several smallholder famers diversified their economic activities in order to generate additional income and reduce extreme poverty, thus contributing to socio-economic development in the rural areas (Reardon, 2001; Demie and Zeray, 2015). Furthermore, smallholder rice producers in Thailand have undertaken diversification as a means of exploiting their land maximally. The farmers produce rice and sweet corn so as to improve their incomes (Pitipunya, 1995). In the same way, smallholder tobacco farmers in Brazil introduced alternative crops such as bananas and fresh vegetable in order to diversify their cropping systems. In doing so, the smallholder farmers have improved the level of socio-economic development in tobacco growing zones (Vargas and Campos, 2005).

Therefore, it is important for smallholder farmers in developing countries to diversify from the subsistence sources of income to other activities for the improvement of their living conditions. Diversification is an important way of helping smallholder farmers to overcome the gap between farm and non-farm activities. Demissie and Legesse (2013), indicate that smallholder farmers in Ethiopia have undertaken a variety of activities in order to support their livelihood as result of poor crop yields. In Kenya, Kanyua *et al*. (2013) found that crop diversification is better off than mono-cropping system as it provides higher incomes. The diversification appears to be an important opportunity for smallholder famers in SSA to open new ways for increasing access to market and reducing the risk of climate change. Abdalla *et al*. (2013) suggests that for agricultural stakeholders in low-income countries to improve smallholder incomes, crop and livestock diversification should be the primary agricultural policy incentive. This will improve the living conditions of smallholder farmers.

Agricultural diversification is an important strategy towards the improvement of smallholder incomes in the least developed countries. West and Central Africa are characterized by the domination of cotton – cereals that are somewhat linked to livestock systems (Kaminski, 2008). In many cotton-growing areas, smallholder farmers have undertaken to diversify their source of income based on high values commodities (cereals, horticulture, livestock and tuber crops). Agricultural diversification is also an important farming strategy that can augment and at the same time generate employment and reduce rural problems such as poverty and food insecurity. (Ellis, 2000) observes that although diversification of crop and livestock systems is important for sustainable agriculture in developing countries, it is a complex strategy. Longpichai (2013) argued that diversification is known for its role to spur sustainable growth in the rural areas and extends its sustainability effect on smallholder farmer incomes. In this situation, diversification serves as link between livelihood strategies and agricultural production (Meert *et al*., 2005). Southern Mali is a dominant cotton-producing region in Mali. Cotton farming is carried out alongside food crops, horticultural crops and livestock system. Cotton farming is a crucial of livelihood a larger %age of the Southern Mali population.

The market prices for cotton are constantly subjected to fluctuations. Consequently, farmers diversify their sources of income as a resilience strategy to the price shocks. The decreasing cotton revenues coupled with the increasing input price prompt farmers to seek for alternative income generating activities. Some of the options of farmers include focusing on diversification of source of income in the agricultural production system under constraints like climate change, rainfall pattern, low prices of commodities and marketing. Under numerous constraints, farmers need to develop new ways of raising their income through agricultural production, non-agricultural goods and services. In the past producers in the cotton zone depended exclusively on cotton farming for their livelihood this ensured their food security and within the country. Abdulai and Crolerees (2001), estimated that on average, about 30% of household incomes in Southern Mali are derived off farm and livestock. In the past two decades, cotton zone has been affected by numerous constraints and changes including demographic, malnutrition, poverty, food insecurity, yield reduction, climate change.

Traore *et al*. (2013) argued that the climate change plays an important role in the yield of commodities cultivated and farmers start to diversify the source of their living conditions. Cotton farming being the main source of income, the fluctuation of price in terms of kilogram also affected negatively the producers from 2008/09 to 2000/10. The price of cotton per kg was between 160 FCFA and 200 FCFA with an average of 182 FCFA (Baffes, 2007; Blanchard, 2010). It is basically cotton farming production zone by excellence, which has achieved very high level of productivity per hectare during the eighties and nineties.

Diversification towards other sources is being considered as a way of increasing contribution of non-cotton farming output of smallholder farmers. Thus, diversification and integrated agricultural production system is the key for the smallholder farmers to respond to increasing demand for animals and vegetable products. Integration of crop and livestock in the cotton areas constitutes a guarantee for the rural population to produce sufficiently, ensure food security and reduce extreme poverty and their incomes.

Country's development priority is centred on improving life conditions for the increasing population in context of changing climate. In Mali, the cotton area has responded to two problems: to produce enough to cover the food demand and to ensure economic improvement (Soumare, 2008). Income from cotton has permitted the farming families to acquire livestock, thus starting progressive integration of crop and livestock system in cotton areas (Djouara *et al*., 2006).

### 1.1.1. General presentation of Mali

Mali is one of the countries in West Africa. It is a landlocked country to the South of Sahara. It covers an area of 1,241,138 $Km^2$ squared where nearly 60% is a desert area. The population estimate in 2009 was 14 500 000 people (General Census of Population and Housing, 2009). According to the same source, the rate is growing by 3.6%. Malian population of 77.5 % resides in rural areas (RGPH, 2009) and 86% practice agriculture. With a feeble Development Human Index and which takes place in 176 out of 187 countries classified by WFP, 2014, the rate of illiteracy in urban areas stands at 43.2% against 76.3 % in the countryside. Approximately, 64.2% of male are illiterate against 73.2 % of the female. Mali borders Mauritania and Algeria in the north, Niger to the East, Burkina Faso, Cote Ivoire and Guinea in the south and Senegal in the west. Mali is the second producer of cotton and third producer of gold in Africa. The agricultural and mining sectors dominate the economic activities in Mali and are the main source of economic growth.

The Agricultural sector provides over 70% of export, income and employ more than one-third of the labour force. Mali remains one of the world's poorest countries. Agriculture (mostly subsistence farming), livestock and fishing occupied 70 % of the population's activities and accounted for about 35% of GDP in 2008 (Staatz *et al*., 2011). Geographically),

Figure 1 Mali is characterized by alternating two seasons: a dry season and rainy season. The temperature goes as high as 42°C in May and with a minimum of 13°C in January. Mali has four big climatic zones:

**Sub Saharan and Saharan zone**: An average of rainfall is about 150mm per year. It covers almost 57% of national territory and extends to the northern part of the country in the regions of Kidal, Gao and Timbuktu. It corresponds to the desert zone of the country. The ligneous production is feeble, the temperature rises with a yearly average of 30°C. This zone is dry and thus only livestock nomadism and transhumance are practiced (Berthe *et al*., 1991).

**Sahel zone:** This covers more than 18% of national territory. It is divided into two zones: north zone Sahel and south zone of Sahel. The rainfall is between 200 to 550 mm per year. In that zone, there is a huge wet valley located in the Sahel called Niger valley. The presence of water in this zone offers a great opportunity for irrigation, fishing and livestock (Berthe *et al*., 1991).

**Sub-wet zone:** It covers around 14% of national territory. This zone is divided into two zones, that is: the north sub humid and south sub humid. The rainfall is estimated to be between 500 – 1100mm per year. Vegetable production is relatively important. Characterized by the savanna with great trees and abundance of grasses the bovine from north temporarily occupy the region due to its favourable climate. It is characterized by the arboreous savanna and the shrubby (*Acacia sp, Combretum sp, Piliostigma reticulatum). It has* wild fruit for human consumption such as *Andansonia digitata, Parkia biglobosa, Vitellaria paradoxa, Ziziphus Mauritian* among other. The vegetable cover (herbaceous) is dominated by Andropogon gayanus, Cymbopogon giganteus, Andorpogon spseudapricus among others (Berthe *et al*., 1991).

**Sub humid Guinea*:*** It covers around 11% of national territory. An average rainfall per year is over 1200 mm. It is located in the extreme south and South –West of the country, the regions of Sikasso and Kayes. This area preserves again the rich biodiversity. The existence of vegetation and wild animals is important. It is an excellent zone of agricultural production, where we have cotton, maize, groundnut, millet and sorghum. Its vegetation is dominated by the natural formation of trees such as *Lannea velutina, Terminalia avicennioides, Isoberlinia doka, Daniellia oliver*i (Berthe *et al*., 1991).

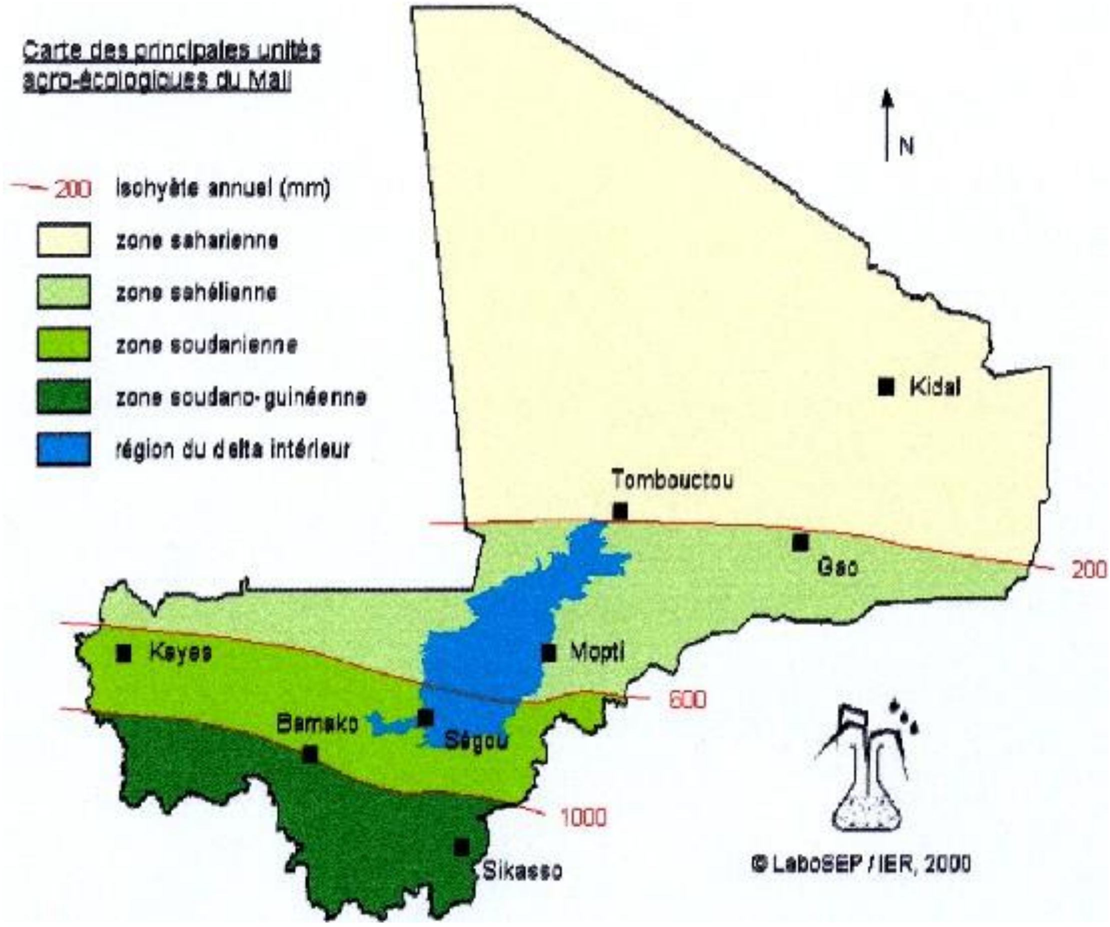

Figure 1: Map of main agro-ecological zones of Mali

### 1.2. Statement of the problem

Cotton farming was introduced in Southern Mali in 1974 in order to increase agricultural productivity and incomes of smallholder famers. The introduction of cotton farming in this region has had a positive impact on agricultural productivity (crops and livestock) and the living conditions of smallholder farmers. Figure 2 shows (1) the success story of cotton farming that the smallholder farmers have earned; high incomes, invest in livestock (draught power and cows) and savings. Despite (2) its significant contribution of cotton farming to socio-economic development in Southern Mali over the last decades, there has been declining cotton yield per hectare and income. Income generated from cotton farming is insufficient to cover the increasing cost of living of smallholder families. In addition, the yield per hectare has been declining despite the continued increase in arable land allocated to cotton farming, thereby leading to low income. Furthermore, research institute such Institute of Rural Economics (IER) and the Company (Company Malian of Textile Development) have generated and promoted the use of improved technologies for increasing agricultural productivity in the region. These institutions have also trained cotton producers on good agricultural practices. However, the yield per hectare for both cash and food crops remains low. As a result, smallholder farmers have undertaken diversification (3) of their sources of incomes to overcome food insecurity, low income and poverty levels. To supplement the revenue from cash crop, smallholder farmers opt to diversify strategies by combining crop, livestock and non-farm activities. Therefore, this study was focused on the diversification of the sources of incomes of smallholder farmers in Southern Mali to determine the factors influencing diversification and practices applied in an integrated system.

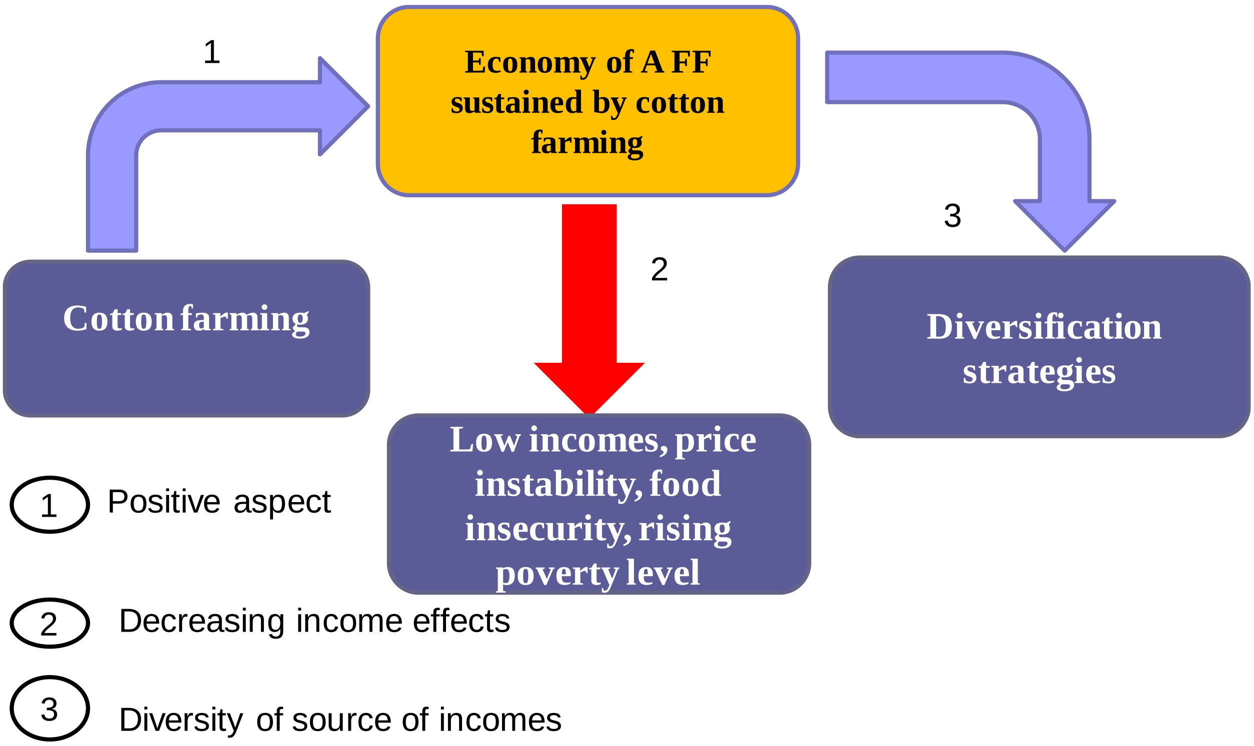


Figure 2: Statement of the problem of the study

### 1.3. Objectives of study

#### 1.3.1. General objective

This study contributes to improvement of the livelihood conditions of smallholder farmers in Southern Mali through enhanced farming and income diversification.

#### 1.3.2. Specific objectives

The specific objectives of this study were:

**(i).** To determine the dynamics of smallholder farmer's agricultural production systems and multiple sources of agricultural income in Southern Mali.

**(ii).** To determine the socio-economic factors influencing smallholder farmer's crop diversification in Southern Mali**.**

**(iii).** To determine the level of technical efficiency and agricultural technology practices applied by smallholder farmers in Southern- Mali.

**(iv)**. To simulate collective decision of farming systems to understand and predict the dynamics of smallholder farmer's income.

### 1.4. Research questions

**(i).** What are the dynamics agricultural production systems of smallholder farmers and multiple sources of agricultural income in Southern Mali?

**(ii).** What are the socioeconomics characteristics influencing smallholder farmers' crops diversification strategies in Southern Mali?

**(iii).** What are the level of technical efficiency and agricultural technology practices by smallholder farmers in Southern Mali?

**(iv)**. Which options for simulation model can be used to understand the dynamics of income in collective decision in farming system?

### 1.5. Justification of the study

Investing in cotton growing area of Mali is one of the main strategies that the government is using to increase agricultural productivity and reduce extreme poverty levels in the country. That zone has been for a long time a provider of main food crop and unique cash crop growing zone within country (Djouara *et al.*, 2006). Cotton growing area constitutes the major source of potential agricultural area in Mali. More than four million people are smallholder farmers among four regions in cotton zone and depend largely on cotton farming. It provides food security, income, employment, socio economics development, welfare among others. Therefore, the smallholder farmers in the cotton zone are the poorest in the country as opposed to the first policies established by the company in charge of the cotton chain (Delarue *et al*., 2009). Therefore, potential agricultural techniques have been tested, experimented in order to increase agricultural productivity and at the same time enhance the living status of smallholder farmers. Despite these technologies being demonstrated, they have been poorly adopted by the smallholder farmers in the cotton zone and have resulted in low yield per crop and livestock. Moreover, the income from cash crop (cotton) that should cover the expenditure of smallholder farmers is low due to the low price of cash crop per kg in the international market *(*Theriault *et al.*, 2013). In addition, the continuous cultivation of the soils without applying the quantity of organic manure advised by the researchers which for cotton is 5 tonnes per hectare, receive only 3 tonnes per hectare ( Kante, 2001; Diarisso *et al*., 2015). Given these facts, diversity of agricultural enterprises and source of incomes are fundamental in rural areas to achieve economic growth and reduce extreme poverty. Furthermore, despite the effort that has been done in cotton growing zone, there is a need to understand the diversity of source of incomes and agricultural technologies practices adoption by farmers in mixed agricultural production systems. Since the zone lies where the arable lands are increasingly scarce, low fertility, climate and rainfall patterns affect negative agricultural production and the smallholder farmers have to cope with low output per agricultural enterprises. The study is expected to provide empirical evidence towards the source of diversity of incomes and agricultural technology practices adoption by smallholder farmers combining crop and livestock production systems. Findings from this study will contribute to the development scheme in short and long term in an integrated agricultural production, which will be useful as reference tool for policy makers, extension services, non-government organizations and related studies.

### 1.6. Scope and limitation of the study

This study was limited to 3 villages in cotton production zone, which covers four regions and 3505 villages. The cotton-growing zone is vast, and therefore it was difficult to cover all the areas in this study due time constraint. However, the selected villages represent similar practices in terms of production system practiced in the cotton zone of Mali. The study was only focused on the diversity of source of agricultural income, diversity of cropping systems, and agricultural technology practices. However, the study did not cover all income generation activities, agricultural technologies experimented and other crop for diversification such groundnut, rice among others which may influence farming family’s livelihood. In addition, collected data were based on farmers’ recall, that could be also biased.

### 1.7. Definition of terms

**Household:** Group of people who are generally bound together by ties, kinship, or joint financial decisions, who live together under single roof or compound, are answerable to one person as the head and share the same eating arrangement.

**Smallholder farmer:** they are sometimes called peasant or resource challenged farmers who own less than 2 ha of land. Farmers rely mainly on family labour for production which is both for subsistence and commercial purposes.

**Non-farming income**: income generated from non-farming activities which are performed on the farm. For example, hand crafting, traditional goldmining, informal trade, salaries.

**Production unit**: it is a group of individuals that produce and consume together, under the responsibility a chief of community, he is also called the head of the family.

**Horticultural production:** it comprises vegetable (tomato, potato, irish potato) and mango, orange, banana…

**Production system**: it is a structural ensemble of vegetables and animal production implemented by the farmers in its unit of production (force work, land, equipment) combined between them to satisfy objectives, the socio economics needs and family farming cultural.

**Crop system**: defined at the level of land or group of land treated in a homogenous manner with same technical itineraries and crop rotation.

**Livestock system**: it is a set of elements by dynamics interactions organized by man to enhance the value of the resources by domestic's animals intervene to obtain the varieties of production or to response to other objectives.

**Cereals:** it refers to main cereals grown in Southern-Mali which are maize, sorghum and millet

**Technical efficiency**: this is the ability of the farmer to maximize output from a given level of input or from a given set of resources

**Farmer Practice:** they are the operations that are implemented by the famers themselves.

**Infrastructure:** refers to the status of road linking the nearest market in the study area.

**Integrated crop and livestock production systems:** An integrated system is a synchronized cropping and livestock system where the waste products from either crop or livestock production serve as a resource for the other.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1. Overall view of agricultural production system

Over the past periods, the world population has been worrying about food insecurity, degradation of ecosystem as well as climate change. These factors are often clear in agricultural production system and researchers as well as policy makers have emphasized the need of agricultural intensification (Rudel *et al*., 2016). Many countries in the world are currently facing a real food shortage problem, which is estimated to increase in the future. Moraes *et al*. (2014) argued that association of crops and livestock system constitutes the major source of income among other farming objectives. They contribute a lot in maintaining ecosystem as well as sustaining agricultural productivity in order to reach food security requirement. The mixed crops and livestock systems appear as the backbone of low income countries as well as developed countries (Bradley, 2010).

This is almost practiced by all types of famers such as large scale and smallholder famers around the world especially in this new century. The rapid growth of population and degradation of ecosystem sensitize the farmers to adopt agricultural intensification through integrated agricultural production system. Franzluebbers (2007), estimated that integration of crops and livestock has been a natural practice in agricultural production system in the world before the time of globalization. Although, integrated crop–livestock systems have been employed globally by farmers in the past century, it has been based on farmer's knowledge and resources (Russelle, *et al*., 2007).

The integrated agricultural production systems have been ensuring a high value product especially at family farming level than mono cropping system. In addition, livestock over the past decades has remained a key component in agricultural sector in Sub Saharan Africa (SSA), since it employs 1.3 billon people as well as supplying food to about 4 billion people around the world (Herrero *et al*., 2009). Its contribution varies between 37% to 25% of the gross value of agricultural production in East Africa and Southern Africa (Rao *et al*., 2014). In SSA, crop and livestock production systems constitute a main strategy for living conditions of rural population (Okoruwa *et al*., 1996).

Agriculture is the dominant as well as the mainstay economic activity in the West African. It provides over 60% of employment to the rural population (OECD-FAO, 2016). According to FAO (2014), the agricultural sector accounts for about 30% of developing countries' Gross Domestic Product (GDPs). The SSA has one the fastest expanding population in the whole world. It is projected that the SSA population be approximately 1.8-2 billion people by 2015 (Samson, 2012). It is important to note that the majority of the people in SSA are vulnerable to multiple problems. Sasson (2012), estimates that about 20% of the African population is underfed and malnourished. Food insecurity is still a major global challenge and approximately one billion people suffer from starvation and are either under or malnourished (Sasson, 2012). FAO (2014), noted that SSA countries were still far from achieving the millennium development goal number one which aims at reducing the levels of poverty and hunger by a half by 2015. It is estimated that SSA countries have about 239 million hungry mouths to feed and this figure is likely to increase in the immediate future (Van Eeckhout, 2010).

Thus, increasing crop and livestock production is seen by some as one of the primary tasks for international development in the new century if food insecurity and poverty in Africa are to be reduced. It is estimated that there will be 9.6 billion people in the world by 2050 (United Nations, 2017). This will be over 30% increase from the current 7.2 billion people. (Fedoroff, 2015) also observes that the world's population will be approximately 10.9 people at the beginning the twenty-second century. Therefore, agricultural development is indispensable in if the world is to sustain the projected population. This achievable since there is an enormous potential increasing the present production in SSA. The demand for livestock products could be doubled by 2050 due to the increasing population and incomes (Herrero *et al*., 2009). This is a viable opportunity for increasing the production of livestock and crops.

Additionally, the rapid increase in population coupled with increased urbanization and improvements in individual and household incomes in developing countries is fuelling a global increase in the dietary demand for animal products (IFAD, 2010). Moreover, it is exacerbating competition between crop as well as livestock enterprises. Despite the smallholder farmers practicing crop and livestock diversification, limited evaluation has been undertaken to ascertain its contribution to the improvement of their livelihoods (Obi, 2013).

**2.2. Diversity of sources of income**

Many smallholder farmers in SSA often have limited access to credit services to purchase equipment and inputs especially during cropping season, thus shift into wage-labour activities to earn cash (Barret, 2001). The formal credits are mainly used in other small businesses outside agricultural production system, and as a result that diversification outside agriculture sector is considered as strongly correlated with the access to credit (Schwarze and Zeller, 2005). Income diversification by smallholder farmers in least developing countries may reduce living conditions problems as well as contributing to increased ability to cope with shocks (Jones and Thornton, 2008). The sources of incomes are diverse, and may include off farm activities which is defined as all activities away from the farming or wage labour, self-employment and rents (Ellis, 2000; Ellis and Freeman, 2004). Therefore, agricultural production activities contribute around 68% of smallholder farmers income in developing countries and the rest about 32 % is generated by nonfarm activities (Schwarze and Zeller, 2005). He argued also that the major source of income in rural area is crops systems, which is about 45 %, businesses and rents 17% and non-agricultural wage labour 15%.

Bigsten and Tengstam (2011), distinguished four types of revenues source generated by small holder farmers in SSA. These are farming, agricultural wage work, non-agricultural wage work and own enterprises. These factors are related to diversification and are driven by endowments such as education level and shifting from a full time farming to more diversified activities that raises the labour income by amount between 25 -100% (Bigsten and Tengstam, 2011). Lay *et al*. (2008), proved that access to extra income augment agricultural production as well as contributing to higher average incomes of Uganda, Tanzania, Malawi and Kenya. In Burkina Faso, Lay *et al*. (2009), reached a conclusion from the panel data from 1994-2003 that the household is better off in off farm activities.

Agriculture is the most predominant economic activity in rural areas in SSA. It offers a reliable option for promoting economic growth, alleviating poverty and improving food security (World Bank, 2008). Diversification of sources of revenues is a norm that few people practice in rural areas (Barrett, 2001). Thus, Lanjouw and Lanjouw (2001), argued that increased diversity of crops, livestock and non-farm activities lead to more rapid growth in consumption and improve the income of smallholder farmers.

The diversification of economic activities and agricultural assets characterize the livelihood strategies of smallholder farmers in rural Africa (Barrett, 2001). In addition, it is estimated that non-farm sources of income have become important. They account for about 35 to 50% of small householder farmers in the region (Haggblade *et al.*, 2010). The smallholder farmer expands the economic activities to increase farm income. Moreover, diversification reduced variability in smallholder income. This because the farmers can exploit new or existing market or non-market opportunities by engaging in wage labour in both on-farm and off-farm activities ( World Bank, 2008;FAO, 2014).

Cotton-cereal-livestock systems in West and Central Africa are characterized by a higher economic reliance on cotton revenues while cereals are a primary source of food. These farming systems rely on livestock and provide relevant strategies for smallholder farmers (Kaminski, 2008). Proctor (2014), estimated the incomes of smallholder farmers from cropping and livestock and found it to vary between 60-80% and differ from one householder to another. Further, Haggblade *et al*. (2009), argued that the non-farm activities contribute about 35% of smallholder farmers' incomes in different countries of Africa. Hence, multiple activities of smallholder farmers in developing countries are the centre of livelihood strategies and increase income. Moreover, smallholder famers change the strategy to diversify the source of revenues and reduce the variability of shocks, that is, practice the off-farm activities and short season migration. In Southern Mali (Cotton zone), cotton remains the dominants cash crop, but it is at crossroads. As a result, smallholder farmers diversify in order to avoid inherent risks. Low levels of purchase prices of cotton in international market, some producers have moved away from it to cereals production and horticultural products which they now generate half of their total income (OECD, 2008). In addition, smallholder cotton producers multiply several ways such as trade in local weekly market, shops, short season migration among others in order to compensate the remainder spending of families need.

**2.3. Crops diversification strategies**

Economic development, food security and poverty alleviation in developing countries is directly linked to the agricultural sector (Pretty *et al*., 2011; Mugendi, 2013). However, agriculture in the developing countries is for subsistence and mainly undertaken by smallholder farmers who constitute over two-thirds of the global poor, food insecure and most vulnerable population (FAO, 2015; Sibhatu and Qaim, 2017). Smallholder farmers in Sub-Saharan Africa (SSA) endured with low income from agricultural production and continue to struggle with food insecurity, poverty and climatic risks (Khatiwada *et al*., 2017). Most of the governments in SSA are faced with the dilemma of achieving food security, while reducing poverty in the face of increasing population, climate change and the associated environmental consequences (Vanlauwe *et al.*, 2014; Kuivanen *et al*., 2016; Binswanger-mkhize and Savastano, 2017). Although smallholder farmers in developing countries depend on rain-fed agriculture, they continue to contribute to improvement of rural and urban livelihoods. For instance, in SSA, agriculture employs over 50% of labour force and contributes to an average of about 15% of the total gross domestic product (GDP) (OECD-FAO, 2016).

Smallholder farmers engage in multiple farm and non-farm activities in order to generate income, enhance food security and reduce poverty by utilizing their farms and selling surplus products (Wan *et al*., 2016). A majority of smallholder farmers undertake more than one activity and generate income from more than one source such as crop diversification, which refers to a mix of farming systems rather than the shift from one given enterprise to another (Babatunde *et al*., 2008; Martin and Lorenzen, 2016; Morris *et al*., 2017). Participation in a mix of activities contributes to increased level of smallholder farmers' incomes and maximizes their income (Khatun and Roy, 2012). Farmers producing cash crops in the developing world diversify their agricultural production systems to increase their incomes, improve and maintain food security and reduce vulnerability to poverty (Goshu *et al.,* 2012*;* Gondwe *et al.,* 2017*;* Dey, 2018).

Agricultural diversification is one of the strategies for income generation, poverty and food insecurity reduction and improvement of nutritional status of rural population (Barrett, 2001;Reardon, 2001; Makate *et al*., 2016; Khan *et al*., 2017). Diversification involves growing more than one crop and, at the same time, practicing livestock production to increase income and enhance livelihoods. However, food crop production, the primary income generating enterprise in rural areas in SSA, is inadequate to enhance the well-being of smallholder farmers. In addition, its contribution to rural livelihoods is hampered by high cost of production ( Abimbola *et al*., 2013; FAO, 2014; ). This is attributed to low input use, low mechanization and poor soil fertility which lead to low agricultural output (Sheahan and Barrett, 2017). Although agricultural diversification reduces production-related risks and increases farm earnings, few farmers diversify their agricultural activities in SSA. The lack of access to agricultural inputs, equipment and other factors of production as well as institutional constraints are important obstacles to diversification (Kasem and Thapa, 2011; Nguyen, 2017). Low or lack of diversification causes a decline in production of important commodities such as cash crops (cotton), food crops (maize, millet and sorghum) and livestock products. Hence, agricultural diversification is important for the improvement of smallholder farmers' livelihoods because of its potential of providing a reliable source of food and income in rural areas.

Several studies have attempted to describe the factors that may influence smallholder farmers in developing countries to diversify. Results indicate that education level, farmers resource endowment, agro-ecological and institutional factors constitute major constraints to farm and non-farm income diversification (Headey and Jayne, 2014; Oyinbo and Olaleye, 2016; Kassie *et al*., 2017). The understanding of smallholder farmers' decisions to participate in a particular strategy from among the available choices should put into consideration the enabling factors or constraints. Smallholder farmers' choices for agricultural diversification are determined not only by agricultural production systems but also by low soil fertility, climate conditions and income among others. Likewise, it is rare for farmers in the rural areas of developing countries to sustain their livelihoods from one source of income. Most farmers in rural areas depend on a diverse portfolio of activities. Moreover, smallholder farmers may engage in crop and livestock production to overcome food insecurity and poverty.

### 2.4. Integrated agricultural production system

Dual-purpose crops are fed to livestock by removing the leafy parts. This allows the crop to regenerate and produce grain (Bell *et al*., 2014). An integrated agricultural system is a synchronized cropping and livestock system. Waste products from either crop or livestock production serve as a resource or input for the other (IFAD, 2010). This relationship could also be competitive or complementary depending on the level of coordination of resources use such as land, labour and capital (Ngambeki *et al*.,2010). In the context of saturation of arable land, the diminishing of soil fertility (poor and acidic soils, lack of fallow land in the cotton zone, and reduced areas for pasture) through, livestock and crop integration appears as an asset to improving both systems. It increases crop yields using manure and also enhances fodder production in a relatively extensive livestock production system (Thornton and Herrero, 2001). They are not sufficient in producing organic matter to maintain soil fertility, permanent ways of cultivation and feed for bovine herd lays a challenge (Coulibaly, 2008). Other important challenges include land saturation, destruction natural resources, lack of land fallowing and maintaining agricultural productivity.

Integration crop and livestock has been promoted since the year 1960, mainly in cotton, groundnut and rice grown areas using animal as draught power (Vall *et al*., 2012). Many smallholder farmers in SSA depend on livestock as a source of organic manure for applying in their food crops or cash crop among others and low input used (Schiere *et al*., 2002). Others practices in agricultural production systems required also mulching, manure application and crop rotations to reduce soil erosion, augment nutrient in soils and assure food from crops more adapted to climate change (Rudel *et al*., 2016). Integrated crop-livestock systems (ICLS) are found to be main component for agricultural development in order to reach the objectives assigned for reducing hunger and extreme poverty in rural areas (Moraes *et al*., 2014). That integration offers an opportunity for smallholder farmers to achieve their socioeconomic development and food sufficiency (FAO, 2014).

Therefore, Haileslassie *et al*. (2009) argued that, by 2020 livestock production will increase more than half of the total global agricultural output in monetary value. In crops and livestock system, their combination can augment productivity and positive effect on environment such as soil erosion, improved drainage into ground water (Ryschawy *et al*., 2012). In this situation, improving water management in an association of crop and livestock should have to play an essential role and advantage for enhancing these components (Descheemaeker *et al*., 2010). Livestock manure remains another important option to meeting the soil-fertility requirements for intensive use of cover crops (Place *et al*., 2003). Furthermore, this couple enhances the economy of smallholder famers in least developing countries and contributes greater food security and more profitability. Animals might be a center in this integrated system because they are able to transform crop residues into high value meat, milk and by products (Oltjen and Beckett, 1996).

High association of crop and livestock systems can transmit fundamental advantage to the agricultural productivity and its sustainability by: (i) more efficiently utilizing natural resources, (ii) exploiting natural pest control processes, (iii) reducing nutrient (Franzluebbers, 2007). In Research and Development way, integration of crop and livestock in Sub-Saharan Africa (SSA) is a vital component in agricultural research because it has a long-term effect on poverty reduction as well as enhancing living conditions of smallholder farmers and the overall economic growth in developing countries (Lenné and Thomas, 2006). Based on agriculture function Bell *et al*. (2014) argued that to be durable, future increases in agricultural production in SSA would have to be managed by the interaction of crop and livestock systems. They constitute a major association than any system in terms of their contribution to the revenues or output of smallholder farmers. Crop and livestock integration allow efficient utilization of farm inputs and marginal land, thus increasing agricultural productivity and farm incomes.

Figure 3 shows a simplified model of an integrated system. It indicates that crops and livestock constitute major entrances of agricultural research (Dembele, 2008). Integrated system has two major components. They include the different cropping enterprises as well as livestock enterprises. Organic manure is applied to crops and the waste is used as livestock feed. These practices supplement the inadequate application of inputs in both enterprises, thereby improving productivity

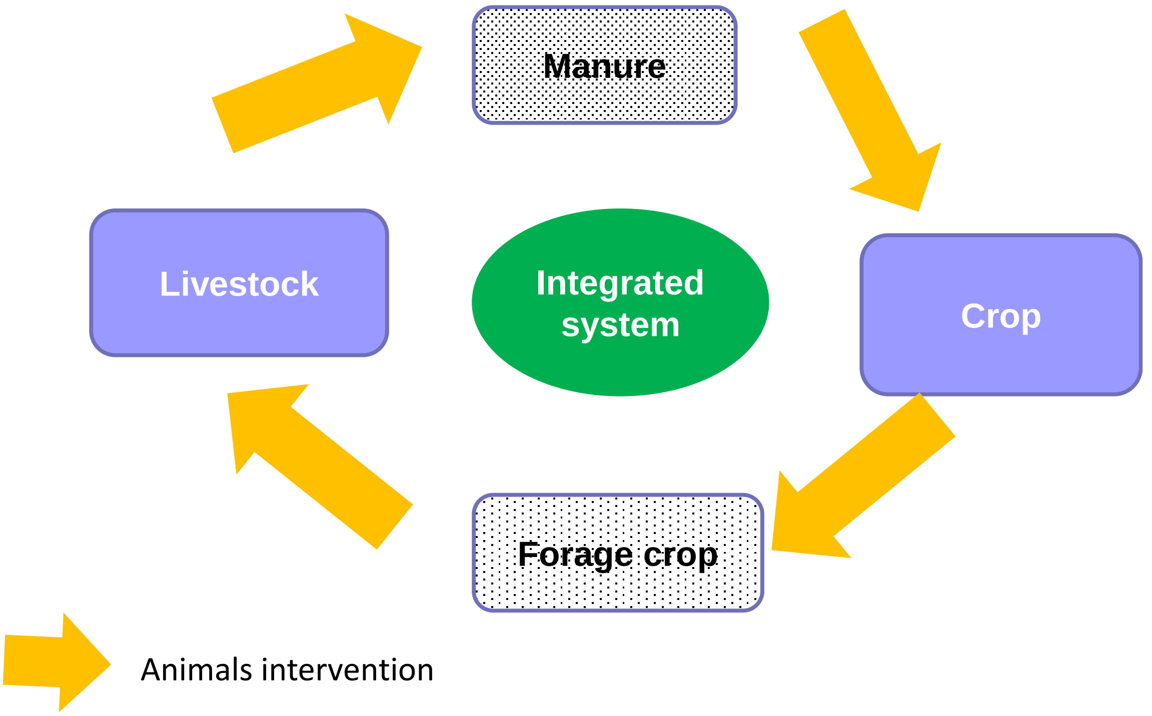


Figure 3: Integrated crop and livestock system
Source: Adopted from Dembele (2008)

**2.5. Agricultural technology practices in Southern-Mali**

Agricultural technology practices are expected to increase the production per hectare as well as to improve the incomes and food security and help farmers to move out the poverty. However, the rate of adoption of agricultural technologies practices is still low and which is opposite to population growth (Ahmed *et al*., 2017). Main causes of low rate of agricultural technology practices adoption include education level, access to agricultural credit and extension services, markets information, access to agricultural inputs such as agrochemical fertilizer, improved seeds (Wossen *et al*., 2013; Wossen *et al*.,2015). In addition, Kassie *et al*. (2012) argued that the most factor limiting agricultural production growth in SSA is soil fertility. Therefore, the increase in agricultural production in the region is due to the expansion of cultivated land (Shiferaw *et al*., 2011;Teklewold *et al*., 2013). In most of countries in SSA, the agricultural sector fails to ensure food security both at national and household level (Bezu *et al*., 2014).

Empirical studies pointed out that the adoption of agricultural technology practices contributes to the reduction of extreme poverty, malnutrition and improves the livelihood in rural areas (Shiferaw *et al*., 2014; Khonje *et al*.,2015). Agricultural technology practices adoption refers to the improvement of productivity per capita, low inputs use which is related to low cost of production and results to the improvement of rural livelihoods through increased income. The adoption and diffusion of agricultural technology practices constitute a major challenge in development of agriculture. In agriculture sector the adoption of different package of technologies by smallholder farmers is constrained by various socioeconomic, institutional and environmental factors (Mariano *et al*., 2012). Indeed, most of studies have attempted to understand the role of agricultural technologies adoption and its effects on farmers' well-being and output at plots levels. The adoption of the following practices can improve output per hectare, that is, adoption of improved seed, practicing conservation tillage, legume intercropping, soil and water conservation, using agrochemical fertilizers, legume crop rotation, application of organic matter among others (Teklewold *et al*., 2013; Kassie *et al*., 2015; Ahmed *et al*., 2017;Wossen *et al*., 2017) . The impact of these agricultural technology practices is significantly related to socioeconomics, institutional factors, market access, improved water technologies, social capital among others.

Agricultural technologies have been promoted in cotton production zone in Mali over thirty years through agricultural research institution such as Institute of Rural Economics (IER) and extensional services of Malian Company of Textile Development (CMDT). Several agricultural technology practices such as agrochemical application techniques, production of manure, different ploughing systems, sowing techniques, rotation cotton-maize, cotton- sorghum –millet, association maize leguminous, fodder crops, among others have been demonstrated at farmer's level. Despite, all those availabilities of technologies in Southern-Mali, the region records the highest number poorest farmers and high rate of malnutrition in the country (Delarue *et al*., 2009). The population is continuing to increase and arable land is decreasing and over cultivation resulting to shorter fallow period in many villages. However, the production of main crops, for example cotton, maize, millet and sorghum per hectare comes from the expansion of land size under cultivation. This results to land degradation, low productivity and continuous cropping in the region (Gigou *et al*., 2004). In cotton belt of Mali, several studies have been conducted, focusing on demonstration of agricultural technology practices and adaptation of climate change of sustainable agriculture (Traore *et al*., 2013;Traore *et al*., 2015; Sanogo *et al*., 2016). While a few studies have attempted to analyse agricultural technology practices in cotton production zone of Mali demonstrated in the past and their rate of adoption. The study uses multiple econometric model such as logit regression, multivariate probit and bivariate probit to understand the determinants agricultural technology practices in cotton production zone of Mali.

## 2.6. History of Cotton in West and Central Africa

The Association for the Development of Cotton Production (ADCP) was established in the 1860s in Manchester as an institutional initiative by industrialists who were concerned with the supply difficulties in the cotton value chain. Instantly, trials were launched in Gambia and Sierra Leone, and later in Nigeria. England established the British Cotton Growers Association (BCGA) in Nigeria in 1903. On the other hand, France focused on Senegal, which had a long-standing cotton production tradition. France's attempt to introduce cotton in Casamance in the Senegalese Valley was unsuccessful.

In the 1930s, French opened a Niger-Mali office which was initially designed for cotton production under irrigation. However, the initiative was unsuccessful. Finally, these were the savannahs of French Equatorial Africa (AEF), lying between Cameroon, Chad, and the Centre African Republic, that have constituted the first major cotton basin. Since the 1970s, the latter is still the largest basin in the region. It produced 42% of West African cotton production ahead of the Nigerian Basin which produced about 38% (OECD, 2006).

In 70 years have been the creation of companies mix economies such: CotonChad in Chad, CIDT in Cote Ivoire, Sodefitex in Senegal, Sodecotton in Cameroon, CMDT in Mali, Sofitex in Burkina Faso, Socada in the Republic of Centrafrica, Sonapra in Benin and Sotoco in Togo. Indeed, the cotton constituted one of the main product exported by the West and Central Africa: 15% of world cotton exportations come from nine countries of West Africa. The income generated by that product constituted an essential resource in the lives of many rural communities these under-regions. West and Centre Africa are relatively weak in terms of representing a world production of cotton (5%), but these regions are responsible near 13% of world exportations (Bakoyoko, 2013).

Cotton constituted one of the main success stories in agriculture in the Francophone from Sahelian countries, a result of cheap family labour compared to the developed countries (OECD, 2005). It contributes to the improvement of income, livelihood and access to the social services such as schools, roads, and health centres. It equally contributes to the improvement of cereals production. This is attributed to improved cropping practices such as of crop rotation and the adoption of innovations.

## 2.7. Production of cotton zones in Africa

There are five basins of cotton producing zones in Africa Figure 4. The largest cotton production zone is in West Africa. It stretches from Senegambia to South Eastern Chad and to the heart of the Central Africa Republic. It accounts for about 60% Africa total cotton production (OCDE, 2006). Cotton production zones stretch from the North–South Strip and Nile Valley to South Africa. The largest zone is the Egyptian basin which offers 15%. It is followed by Southern African Basin which contributes about 13%. The Great Lakes and the East African Basins contribute 6% each. Therefore, cotton is cultivated in all the sub-humid and semi-arid with an annual rainfall of between 500-700 mm and 1200-1500mm. Hence, cotton is found in Northern zones of the coastal countries (Benin, Cameroon, Cote Ivoire, Togo, and Nigeria) and the Southern zones of the landlocked countries (Mali, Burkina Faso, Niger and Chad).

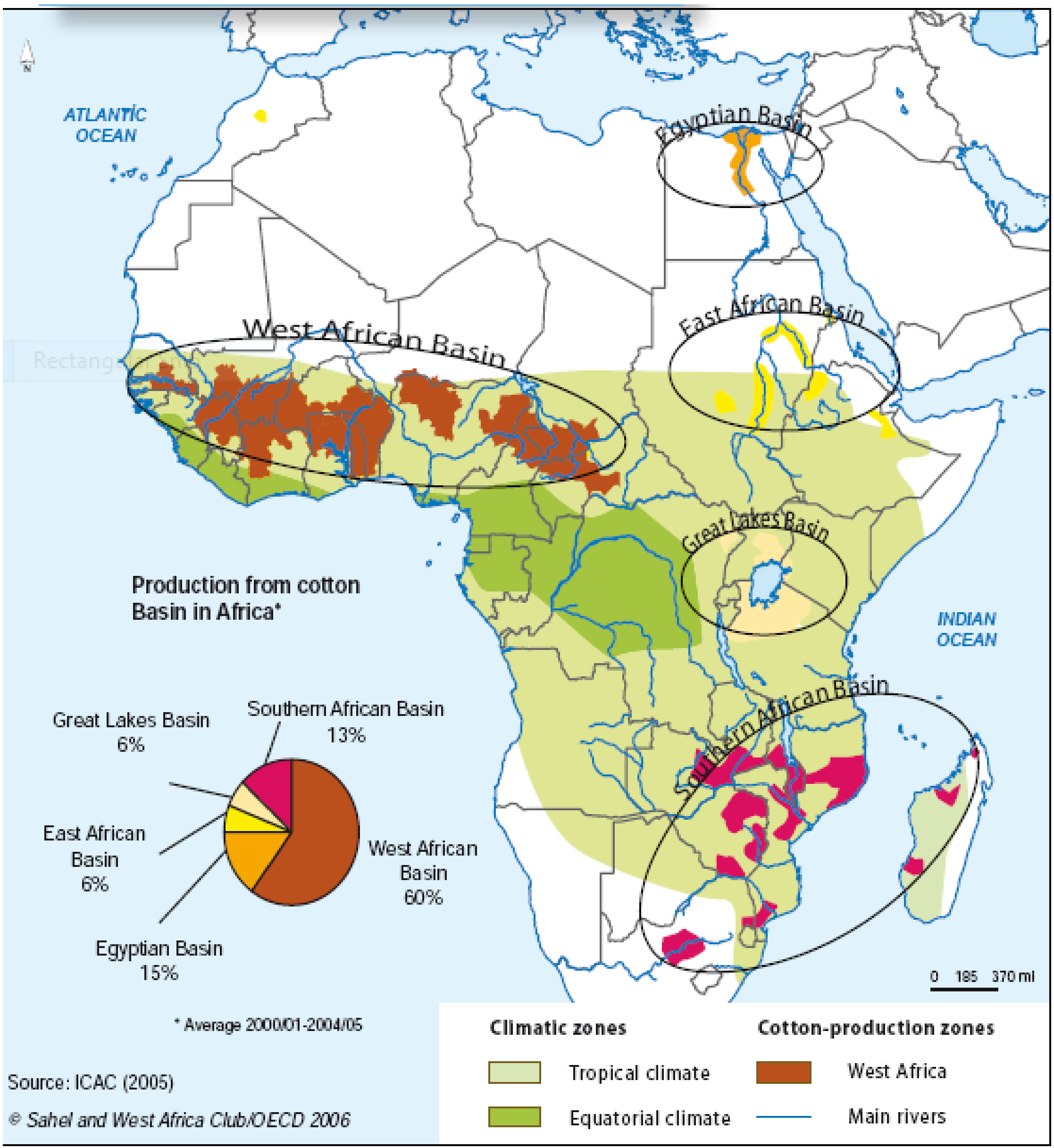


Figure 4: Cotton production basins in Africa
Source: (OCDE, 2006)

### 2.8. Characteristics of Cotton area in Southern Mali

Cotton constitutes an essential cash crop in the agricultural sector in Mali. It directly supports to about three million people in the country. The cotton represents around 14% of GDP (693 billion FCFA), it provides 98.8% of agricultural exportation receipt, and it is the second in terms of total exportation after gold (CMDT, 2005). The challenge agriculture is facing in Mali is its multiple environmental and socio-economic constraints; to produce more, satisfy food requirements and contribute to the global economy. There was spectacular development of cotton in Mali under the projects such as South-Mali and CMDT (Malian Company of Textile Development). Cotton production grew from 60 000 tons during the years 1975 to 600 000 tons in 2005 (CMDT, 2005).

### 2.9. Dynamics of cotton production in Mali

Cotton is a strategic crop in Malian economy. More than 300 000 rural families cultivate Cotton and a third of Malian population has their revenues from cotton cropping (World Bank, 2011). The government forecasts to double the production in five years from 440 000 tons in 2013 to 800 000 tons in 2018 by increasing the input subsidies of cotton. Improving the cultural techniques has increased the yield from 900kg/ha to 1200kg/ha. The period of 1970-1980 marked the first boom of cotton cropping and significant growth in yields due to appropriate application of the phytochemical products and chemical fertilizer and at the same time the hectares had doubled from 50 000 to 100 000 ha. A second boom is from 1980 to 1995, where the production increased from 100 000 to almost 500 000 tons due to hectare extension, which stretches from 100 000 ha to 400 000 ha.

### 2.10. Cereals systems (maize, millet and sorghum) in Southern- Mali

In Southern – Mali, cropping system is based on the rotation of cotton and cereals mainly maize, millet and sorghum. The rotation system is a biannual cotton-cereals and three annual cotton-cereals-cereals. That rotation system allows cereals to benefit on the residual effect of fertilizers used in cotton. These cereals are used for home consumption as well as marketing. Therefore, maize cropping plays a double role regarding food security and cash generation. Indeed, the arable land allocated for main cereal crop fluctuates from one commodity to another one. Over the last ten years in cropping season mainly from 2003/04 to 2012/13, on average the allocated land size was 478,948 ha for sorghum, 346 992 ha for millet and 268 459 ha for maize respectively (Sissoko *et al.*,2013). The allocated land size explains the feeble arable land allocated for maize in cotton which was declining during the same period. The decreasing size of the land area allocated for cotton had affected the land size under maize because maize benefited from fertilizer used in cotton. Yield per hectare for millet and sorghum was on average 1ton and for maize was on average 2500kg per hectare (Sissoko *et al*.,2013).

**2.11. Livestock production system in Southern-Mali**

Livestock (cattle) rearing is one of the most important factors in the agricultural development in the cotton belt region. It mainly contributes to draught power, organic matter, the source of savings and food security. In cotton production zone, about 90% of farming families possess some cattle herd including oxen. It is an important source of income for the rural population because it contributes to almost 80% of income for the pastoral system in northern part of the country and 18% for the agro-pastoral zone in southern (Alary and Dieye, 2006). According to National Statistics Institute INSTAT (2009), livestock constitutes the third export values in Mali after gold and cotton with about 41.2 billion of Fcfa.

In cotton production zone, the company in charge of cotton promotes inputs, access to agricultural credit, oxen for draught power and agricultural tools for cultivation. These interventions led to an increase in the number of oxen for traction, and the revenue from cotton production is also invested in breeding cattle. Cotton belt has been considered as crop and horticulture zone, and it has become a second zone of livestock production region with approximately 1.4 million of cattle (DNPIA,2010). In cotton belt, there has been an increase in the number of cattle leading to direct consequences such as increased population growth and extended cultivated land size.

Regarding feeding systems, animal mainly depends on natural pasture as well as utilization of crops residues after harvesting. In certain areas where the population pressure is increasing, there are problems associated with natural resources as well as the lack of fallow land, leading to competition between cropping system and livestock system. During the dry season, a good number of herds migrates for a long period of transhumance, with only oxen and three or four cows remaining in the village. Farmers store the residues (leguminous and crop) for feeding the herd. Besides, farmers also use the concentrated feed to maintain oxen in good status for land preparation at the beginning of every season. Livestock (cattle) is the heart of agricultural development in the cotton growing zone of Mali due to its positive impact on agricultural productivity and farming family welfare.

## 2.12. Cotton: the driver of agricultural development

The introduction of cotton in Southern Mali has contributed to deeper transformations in agricultural practices. It has provided an incentive to the farming families to own equipment which has encouraged intensification, leading to the promotion of crops such as maize, sorghum and millet. The %age of the number of the agricultural farming families owning equipment (cart, plough, seeder) has increased from 10 % to 80% and the number of oxen for ploughing has multiplied by six from 100 000 to 600 000 in 30 years. Hence, the zone has become of livestock growth by excellence. Ownership of equipment has come along with increased intensification which has been marked with unprecedented increase in the use of inorganic fertilizers and using manure. The number of hectares under cultivation rose by an average of 6% per year until 1990. In some village in the old basin, the area of land under cultivation increased by nearly 80% (Gigou *et al*., 2004).

## 2.13. Socio-economic impact of cotton in Southern Mali

Cotton cropping is the largest agricultural activity in Southern Mali and it is a major contributor to the national economy. Cotton is the leading source of revenue for major agricultural producers in southern Mali. Cotton was the main cash crop export earner in Mali claiming around 200 billions of Francs CFA in 2003, (Insat, 2004). According to the CMDT, cotton assures direct revenues to more than 3 million Malians (30% of population). More than three-quarters of agricultural family exploitations have a complete plough (oxen and plough) (Sanogo *et al*., 2010). Moreover, there are some agricultural farming families have a tractor and other machines. Production cost is among the feeble in the world, (Djouara *et al*., 2006; Soumare, 2008). In the last 30 years, Malian cotton has been considered as one of most successful agricultural practices in Sub-Saharan Africa with key elements of that success being: technical, ecological, economical and socio-political. The CMDT promotes the construction of roads, schools, health centre, training of adult in the local language, veterinarian services, factories, qualified artisans, transportation. Due to cotton, the producers can have access to credit to produce cotton and others crops, purchase feeds for livestock, TV, solar, among others. The revenue from the sale of cotton is a source of livestock development in the cotton area. It is also the main source of household income. The improvement in revenue coupled with level of nutrition and health has certainly been favouring demography growth and livelihood.

### 2.14. Theoretical framework

#### 2.14.1. Production theory of the firm

Production involves transforming inputs into outputs. The theory of the firm is focused on the idea of reasonable maximization of resources used in the production function. The production function supports the theory of the firm. It allows to describe the current state of technology and how inputs can be transformed into outputs (Coelli *et al.*, 2005). A farming family production function can be expressed as:

$$Y = f(X) \qquad (1)$$

Where $Y$ is the total output of cotton, maize, millet and sorghum and X is the variables included in the production process such as land, land and capital. The production function assumes the properties of non-negativity monotonicity, concavity and weak essentiality. The non-negativity assumption ensures that the function $f(X)$ results only in zero positive outputs from production. Monotonicity implies that additional units of inputs used in the production do not decrease the total production and therefore the marginal products of inputs used in the production are expected to be non-negative. The concavity assumption restricts the output obtainable from a linear combination of inputs to be no less than the sum of the outputs obtainable from each input on its own. Weak essentiality indicates that positive quantities of at least one of the inputs used, planting material, are necessary to produce any crop (cotton, maize, millet and sorghum). The weak essentiality assumption is valid because it is not possible to produce any crop without any planting material.

The main objective of a producer is to maximize profit either by increasing the quantity of output $Y$ or by reducing the cost of producing $Y$. The production function shows the maximum quantity of good that can be produced using alternative combinations of factors of production.

This study is based on the production theory and utility maximization theories. The smallholder farmer's choice for livelihood strategies can be conceptualized using a random utility model (RUM). RUM is particularly appropriate for modelling discrete choice decisions, and it is an indirect utility function where an individual farmer with specific characteristics associates an average utility level with each alternative strategy in a choice set. Approaches are based on production function, profit function, cost function and gross margin. The Cobb-Douglas specification provides an adequate representation of the production technology, if emphasis is placed on efficiency measurement and not on an analysis of the general structure of the underlying production technology. The Cobb-Douglas model is flexible and widely used in agricultural economics (Battese *et al*., 1992). It is illustrated by Cobb-Douglas function presented in equation (2):

$$Y = AL^{\alpha} K^{\beta} \tag{2}$$

Y = Output;

L= labor input;

K= capital input;

A = technical factors and

$\alpha$ and $\beta$ are the output elasticities of capital and labor.

Income and crop diversification in an integrated system, which can be done through various approaches, but this study, is interested in an economical approach. The economic model in this case provides a model of how to make a logical sequence of relationships among several variables of interest to achieve the stated objectives of this study. In addition to this study, the simulation model of integrated agricultural production system was used to predict the variability of production and explain how the interaction of crop and livestock can be a factor for improving the livelihood of smallholder farmers. Integrated agricultural production system touches on the crop system and livestock system. The analysis of integrated system is concerned with use of quantifiable data, and data concerning the local knowledge of producers on the variability of production system.

**2.14.2. Concept of stochastic frontier production analysis (SFA)**

The production function is defined as the given maximum possible output for a given set of inputs. Therefore, it is a boundary or a frontier (Battese & Coelli, 1995; Mastromarco, 2008). However, all the production units on the frontier should be fully efficient. Thus, technical efficiency can be defined as situation when a farmer produces maximum level of output from a given level of inputs. Technical efficiency can be analyzed using either the deterministic or the stochastic frontier production function.

The deterministic frontier part of production function, the entire shortfall of observed output from maximum feasible output is attributed to technical inefficiency, while the stochastic frontier analysis (SFA) includes the effect of random error to the production frontier. There are two techniques of estimating the production function. One is a non-parametric approach called Data Envelopment Analysis (DEA) which uses linear programming technique and the second one is a parametric approach which uses the econometric estimation (Battese and Coelli, 1988).The DEA does not assume any a priori functional relationship between the inputs and outputs and one problem of this approach is that it is extremely sensitive to outlying observations (Aigner *et al*., 1977). The parametric or statistic approach imposes a specification on production function and allows the statistical inferential. Hence, the test of specification hypotheses on the efficiency and other estimated parameters of the production frontier. The potential of production level on the frontier production function estimated as an envelopment surface of observed production data (Battese, 1992). Therefore, a perfectly technical efficiency farmer has TE=1, while an inefficiency farmer has $0 \leq TE < 1$. The value of 1-TE indicates the inefficiency level of a farm.

### 2.14.3. Review of empirical results in developing countries using stochastic frontier production function

Several studies based on stochastic frontier analysis (SFA) have been conducted in agricultural sector in developing countries (Forsund *et al*., 1980; Kuboja *et al*., 2017; Tipi *et al*., 2017). A study conducted by Ahmed *et al*. (2014) to estimate technical efficiency of maize production in Central Rift Valley of Ethiopia reported that the mean technical efficiency of maize was 84.87 %. The study found that access to agricultural extension services, access to credit and soil fertility determines positively the level of technical efficiency. Chang and Wen (2011), estimated the technical efficiency of off farm work and rice production in Taiwan using stochastic frontier production function. The results showed that off farm worker and rice production farmers had the same mean technical efficiency of 81%. In Tanzania, Kuboj*a et al*. (2017) estimated the technical efficiency of small scale beekeepers. Using Cobb Douglas stochastic frontier production function, they found that the mean technical efficiency was 92%. The main determinants in explaining efficiency were contact, follow up by extension officers and access to training. Binam *et al*. (2008), considered the technical efficiencies and factors affecting groundnut monocrop, maize monocrop and maize-groundnut production among smallholder farmers in Cameroon. The mean technical efficiencies were 73%, 75% and 77% for maize monocrop, maize-groundnut and groundnut monocrop respectively. The factor affecting the efficiency of production systems were access to credit and extension services, soil fertility, distance to the road and social capital.

### 2.14.4. Conceptual framework

In this study, the factors involved are categorized into two groups (i) socio-economic and (ii) institutional factors. Figure 5 shows the linkage between the socio- economic and institutional factors which influence production systems. Crops diversification refers to growing of more than one crop. Diversification of crops allows farmers to cope with low income from cash crop, ensure food security and reduce over dependency on one source of income. Most farmers undertake more than one enterprise to reduce risks such as crop diseases, flooding, insects attack, food insecurity among others. Therefore, factors of production and institutional factors can be an obstacle to crop diversification and also they are expected to influence positively farmer's livelihood conditions. The diversity of cropping systems can be influenced by family size, large hectares of arable land exploited among other factors. The level of agricultural equipment is the key factor in determining the capacity of family farm to exploit during the early first rains. The labour is an essential factor of production in the cotton area; it determines the number of labour force available in the family farming. Having livestock (bovine) and land offers a possibility to diversify revenue and at the same time alleviate poverty and malnutrition. Agricultural technologies practiced by farmers are expected to increase crop output as well as to enhance farming systems. However, agricultural technologies practices can be limited by factors endowment of families and intuitional factors thus influencing the output of crop and gross margins. Integrated system involves crop and livestock. Crop residues (biomass) serve as livestock feed, while livestock on the other hand provides a manure for soil amendment. Integration of crop and livestock provides a positive effect on agricultural productivity and on environment. Thus, integrated system constitutes a key component for agricultural development in Sub-Saharan Africa (SSA).

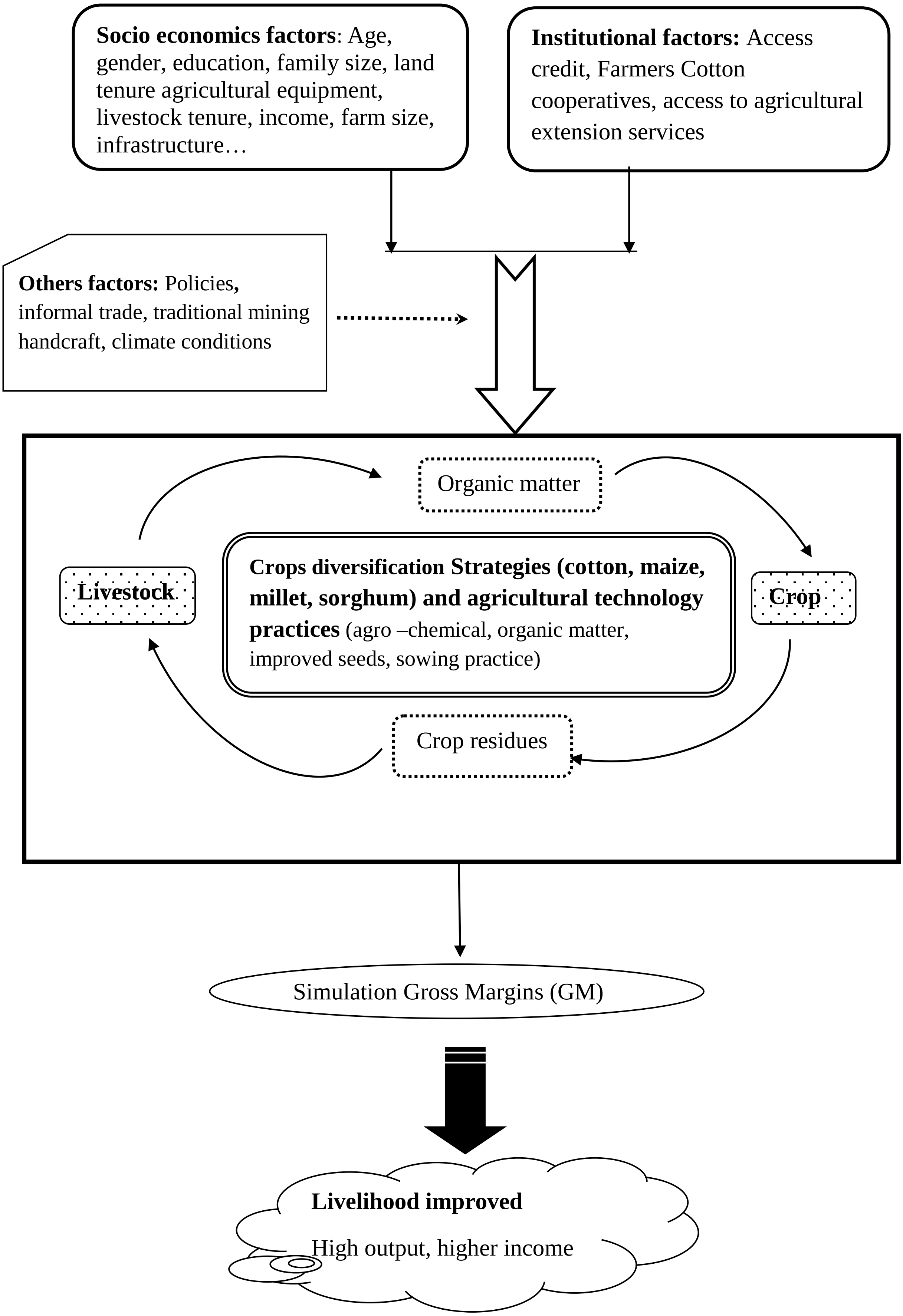


Figure 5: Conceptual framework

# CHAPTER THREE

# METHODOLOGY

## 3.1. Study area

Southern Mali, administratively cover all region of Sikasso, partially all regions from Koulikoro, Segou and the new cotton area called Kayes region. It covers 13 provincials, 79 communes and 3505 villages. An area of about 106 000 km², which is 9% of the national area. Southern Mali is an attic of the country and feeds more than 3.7 million of the population (Deveze and Des Fonaines, 2007). The population is essentially rural (89%) and its economy is largely dependent on primary sector and particularly agriculture which assures more than 80% of Southern Mali production. It is a cotton area by excellence more than 40 years ago. Cotton area of Southern-Mali is located between the isohyets 600mm in northern and more 1200mm in the southern region.

Yearly variation of rainfall level is enough, 15-20% in sub-humid area to 30-50% in semi-arid. Total rainfall and rainy season of the duration increase to the northern towards the southern thus determining three climatic areas. Year is divided by three seasons: dry and fresh season from (December to February), dry and warm season from (March to May) and rainy season from (May/June to October/November): Semiarid area (northern): rainy season lasts from July to October with mean rainfall from 550 to 800mm per year; Transitory area (southern): rainy season lasts from June to October with mean rainfall from 800-1000mm per year; and Sub-humid area (northern Guinea): rainy season lasts from May to November with rainfall from 1000 to 1200mm per year.

The study was conducted in Southern Mali Figure 6. The selection of the study area was justified based on several reasons. Southern Mali has a well-developed and diversified agricultural sector compared to other regions in Mali. Secondly, the region receives enormous public and private investment in agriculture. For instance, the Malian Company of Textile Development, which oversees cotton production over the years has encouraged agricultural production through promotion of smallholder farmer access and use of farm inputs. The access and use of technologies such as improved seeds, manure, crop residues, composting among others have resulted in significant improvement in smallholder agriculture compared to other regions. Lastly, Malian agriculture is rain-fed and Southern Mali has favourable agro-ecological conditions that support diverse agricultural productions systems.

**Northern cotton zone (Begune/old Basin):** It lies at -5. 84498 longitudes and 12. 81824 latitudes.

Characterized by high population density, land saturation, a strong pressure on the natural resources and a strong integration of agriculture and livestock, almost lack of fallow and pasture decrease (fodder missing) leading to long seasonal transhumance of livestock (7-8 months) in year. These zone farmers are highly equipped in terms of ox-plough, donkey and oxen carts, planter among others. It corresponds to old cotton basin from isohyet 600-800mm per year. Village1 called Beguene is the study site located in this zone.

**Intermediary cotton zone:** It lies at -5.8924 longitude and 11.6376 latitude.

Characterized by weak population density compared with northern zone (old cotton basin). It corresponds to the isohyet 1000-1100mm per year. Climatic risk and pressure on the natural resources are weak. There is a lot of culture diversification in family farmers (potato, yam, sweet potato) and fruit plantation (mango tree, orange tree, lemon tree). Village 2 called Ziguena is the study site located in this zone.

**Sub humid cotton zone**: It lies at -5.9658 longitude and 10.5017 latitude.

Characterized by low population density and low mechanization compared to Northern and intermediary zones. In this zone, there is use of ancient restoration system of soil fertility based on long period of fallow. These family farming are oriented toward income diversification based on the plantation of cashew tree. It corresponds to the isohyet more than 1200mm per year. Nonetheless, this zone has begun to show pressure on natural resources, it is the reception of livestock (bovine) coming from the northern part of the country. Village 3 called Nafegue.

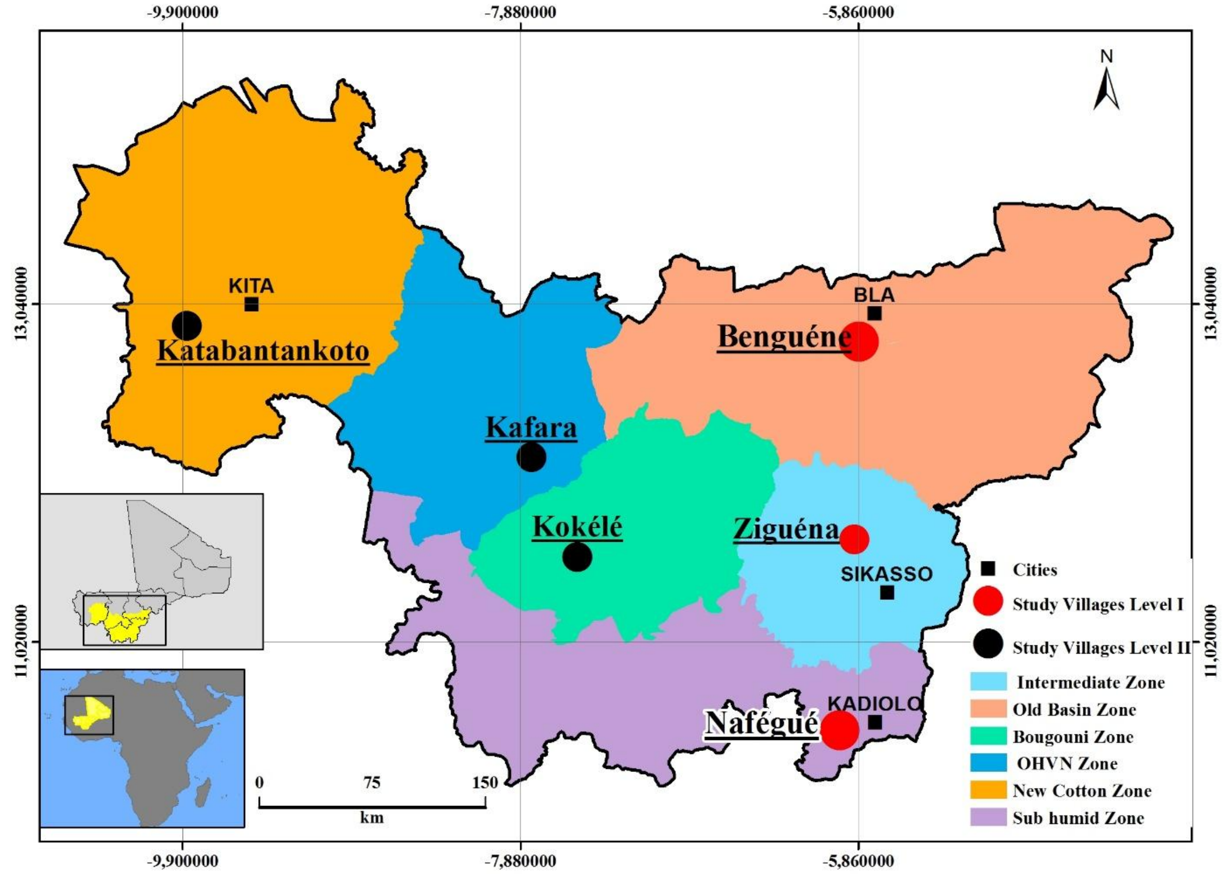


Figure 6: Sites of study area

Source: (Traore *et al*., 2016)

### 3.1.1. Research design

Multiple approaches were used in this study in order to achieve the objectives of research such as using questionnaire and focus group. Data collection was done in each village selected by administering the questionnaire in agricultural farming family selected for primary data. They are based on crop system, livestock system, non-farm activities, agricultural technology practices adoption among others. A focus group was done in each village which involved the older people, women and youth. A dataset has been designed under Microsoft Access as data tools management and statistics analyses were used R and Stata14 for econometrics models.

### 3.1.2. Sample design

In this study, the unit of study was based on the agricultural farming family. In cotton zone of Southern Mali, household does not possess factors of production hence it could be not considered a unit of this study. In cotton area, the producers are organized into Cooperative of Cotton Producers (CCP) in each village. Each CCP has a chairman chosen by members, who oversees listing all cotton producers per year. However, in each village the number of CCP depends on the size of the village. In each CCP, all information is available concerning cotton production: land size under cotton, quantity of fertilizer and pesticide, seed of cotton, cereals, herd of bovine (oxen and breeding) and agricultural equipment such as ox-plough, cart for donkey and oxen, sower among others.

**3.2. Sample size: sample size determination**

The sampling was based on the typology established by the research structure Institute of Rural Economic (IER) and the Malian Company of Textile Development (CMDT) that is responsible of cotton farming in cotton area in Mali Table 1. This typology of agricultural farming family was based on the equipment level: plough, number of ox (livestock) and the cart. This typology is characterized in 4 types, which are:

Type A: Agricultural families farming well equipped with ox plough equipment, with a herd more than ten cattle and have at least two units of yoking or 4 oxen.

Type B: Agricultural families farming equipped, with one pair of ox plough and having less than ten bovines.

Type C: Agricultural families farming, non- equipped but having an incomplete set of ox plough

Type D: Agricultural families farming, non- equipped, but working by hand.

To have more reliable results, the stratified random sampling was used. The total number of agricultural farming families in 3 villages selected is 202. This means the sample size was 134 agricultural farming families which is obtained from (Yamane, 1967) theorem. Random sampling was then applied until the desired sample size will be obtained. The general formula is given by:

$$n = \frac{N}{1 + N(e)^2} \quad (3)$$

n= sample size = 134

N= number of agricultural families farming = 202

e= level of significance at 0.05 confidence level

1= constant value

$$n = \frac{202}{1 + 202(0.05)^2}$$ = 134 Agricultural farming families

Table 1: Number of agricultural farming family by type and by sample size

| Villages | | Type A | Type B | Type C | Type D | Total |
|---|---|---|---|---|---|---|
| Beguena | Number AFF | 32 | 22 | 6 | 7 | 67 |
| | Sample size | 21 | 15 | 4 | 5 | 45 |
| Ziguena | Number AFF | 26 | 15 | 17 | 9 | 66 |
| | Sample size | 17 | 10 | 11 | 6 | 44 |
| Nafegue | Number AFF | 40 | 23 | 6 | 0 | 69 |
| | Sample size | 26 | 15 | 4 | 0 | 45 |
| **Total** | | 64 | 40 | 19 | 11 | 134 |

**Example**

$$TypeA = \frac{134 * 32}{202} = 21$$

### 3.3. Data collection and analysis

Both primary and secondary data were used in this study. Data collection was based on cross-sectional data. Primary data were collected through interview using a structured questionnaire. The data collected were: (i) characteristics of smallholder farmer’s endowment and institutional factors (ii) cropping systems mainly (cotton, maize, millet and sorghum), (iii) livestock production system (iv) income sources and (v) off-farm activities. Focus group discussions were conducted in each village to obtain supplementary information. The discussions involved a limited number of persons. Discussions were about production system in each village. Information collected was related to land ownership and management, constraints in production system (crops and livestock), environment, sources of income and off farm activities. A dataset was designed under data management tools: Microsoft Access. R version 3.3.2 software was used to establish farming family typology and Stata version 14.0 was used for descriptive statistic and for econometric models.

The research unit was the agricultural farming families. The study used two sources of data. Primary cross-sectional data was collected through field surveys of the three villages. On the other hand, panel data was obtained from CMDT, a company in charge of cotton production in Mali. The first panel dataset spanned from 1961 to 2014 and contained information on the total cultivated area under cotton and yield. Another panel dataset spanned from 1974 to 2014 and provided information on the number of agricultural farming families involved in cotton production. Three districts were purposively selected at the first stage, then three communes at the second stage and finally one village was selected from each commune. In total, 134 agricultural farming families were randomly selected following the stratified typology that was established by the research institute of Rural Economic (IER) and the Malian Company of Textile Development (CMDT) based on the level of equipment (ox-plough, cart, oxen and breeding cattle owned).

### 3.3.1. Objective one

To determine the dynamics of smallholder farmer's agricultural production systems and multiple sources of income agricultural in Southern Mali.

Descriptive and inferential statistics were used to analyse data collected for objective 1. Thus, the percentage, standard deviation, means and the F-test and Chi-square of significance were computed. To characterize the dynamic of agricultural farming family in order to obtain a cluster, the software R was used by PCA (Principal Components Analysis) and followed by Ascending Hierarchical Classification (AHC) from the variables characteristics. The tools MVA (multivariate analysis, R Core Team) and ADE4 were applied.

**Choice of structure for explanatory variables of agricultural farming families**

In classifying the smallholder farmer dynamics, some key variables have been selected based on their functional weight on smallholder farmers' endowment. For that purpose, ten explanatory variables have been selected as well as describe well the structure of agricultural farming families in Southern Mali. They constitute the principal factors of agricultural assets in Southern Mali. They include age of agricultural farming family's head, family size (population), equipment (ploughs, carts, seeders), herd size expressed in Tropical Livestock Unit (TLU), number of oxen possessed: 1 Unit for (bull and ox), 0.8 for cows, 0.5 for (heifer and bull-calf), 0.2 for calf and 0.2 for small ruminants, total farm size (hectare), allocated hectare for cash crop (cotton), allocated hectare for food crops (maize, millet and sorghum), organic matter production and number of workers. The variable of education has been omitted in the analysis as heads of families in this research have not received formal education. Gender is not considered here due to non-female headed farming families in Southern Mali. The structured variables identified above as determinants of agricultural farm dynamics. To distinguish and group similar farmers, Multivariate Analysis (MVA) and ade4 have been used. The analysis is run using R3.3.2 software through Principal Component Analysis (PCA). We used a histogram of proper values to determine the contribution of variables to form plan factorials axes.

Principal Components Analysis (PCA) is a method used to describe the variability of correlated variables by smaller set. It allows graphical characterization of smallholder farmers using quantitative values through information continuity in the dataset. It also allows understanding of how the individuals are related and distinguished. Ascending Hierarchical Classification (AHC) or Clusters Analysis (CA) is a method which regroups a group of homogenous smallholder farmers. In this research, we use (AHC) in order to have a group with resemblance and can be represented graphically in dendrogram or clusters.

PCA was employed to establish agricultural farming family dynamics in Southern Mali based on the structure of their agricultural systems and the perceived functions of livestock. PCA has been used in Europe, Asia and Africa in the past to classify and differentiate types of smallholder farmers and also to define their development (Alvarez-Lopez *et al*., 2008; Robels *et al*., 2008; Rao *et al*., 2014; Todde *et al*., 2016). This statistical method has been used to simplify the classification of a large number of smallholder farmers into types or classes that are easily understandable. A similar method was used to describe the level of equipment ownership and socio-economic characteristics of dairy farmers (Robles *et al*., 2005; Pienaar and Traub, 2015). On the other hand, Faruque *et al*. (2014) applied PCA to differentiate production systems crop, livestock and fishery production systems in different locations in Bangladesh. The categorization of smallholder farmers and agricultural production systems in the least developed countries is useful in understanding, intervening and making future decisions with regard to research and investment. For example, PCA has been used to classify different farm activities in urban and semi-urban agricultural systems in Nigeria, Burkina Faso and Mali (Dossa *et al*., 2011). The typology of smallholder farmers in cotton growing zone that was established by IER and CMDT in twenty-two years ago is still being used for research and development purpose. However, IER and CMDT classification only use equipment and cattle owned to classify the farming families. However, with rapid demographic change and the level of equipment used in agricultural production, there is need to develop a new classification of agricultural farming families in the cotton growing area in Mali.

**Description of structured variables used**

Explanatory variables can be divided into two categories. The structured variables include the total population, herd size, farm size, number of oxen, tools, area allocated for cotton, area allocated to food crops, functional variables, the number of workers and organic matter.

Agricultural farming family: This constitutes an extended family with the head of family, one or more than one household, working on the same plot and eating together. The principal feature is family labour (men and women) and the decision-making process. The chief decision maker is usually the head of the family.

Age of family head: The oldest person in the family is the family head and is key in the agricultural decision-making process. The age of family head also has a link with livelihood diversification strategies. Total population/family size (the number of mouths to feed). The more the number of people in the family the more resources are diversified. Herd size: it is a key factor of resource endowment of farming families in Southern Mali. It is expressed in Tropical Livestock Unit (TLU). Having a large herd size means savings and source of diversification for income. Total farm size: it refers to the total cultivated land area in hectares either self-owned or owned by the family.

A large farm size allows crop diversification which guarantees high income. Number of oxen: In the context of this research, we differentiate oxen and herd size because numerous agricultural farming families keep oxen only for ploughing. Number of workers/labour: or human capital. Labour is an important asset in rural areas. Agricultural tools for cropping: Plough, seeder, donkey cart and ox cart are the main asset in Southern Mali and allows farmers to intensify their production systems. Area allocated for cotton and food crops is expressed as a percentage of the land under crop rotation system. Organic matter: shows the degree of integration of crops and livestock and capacity of farms to mobilize important quantity of manure.

Econometric model, Multivariate probit (MVP) and Seemingly Unrelated regression (SUR) were applied to determine the factors that influence multiple sources of agricultural income in the study area. Consider the $i^{th}$ smallholder farm (i=1,…, N) facing a decision on whether or not to participate in multiple sources of agricultural income. Let $U_0$ represent the benefit of unique source of farm income and $U_j$ represent the benefit of farmer to choose the $J^{th}$ multiple sources of agricultural income: where J denotes the choice of food crop production (FC), vegetable production (VP), horticultural production (HP); and cattle production (CP). The farmer decides to choose the $J^{th}$ multiple sources of agricultural income if the utility $Y_{ij}^{*} = U_j^{*} - U_0 > 0$. The net benefit $(Y_{ij}^{*})$ that farmer derives from the multiple sources of agricultural income $J^{th}$ is a latent variable determined by observed exogenous variables $(X_{ij})$ and stochastic error term $(\varepsilon_{ij})$:

$$Y_{ij}^{*} = X'_{ij}\,\beta_j + \varepsilon_{ij} \qquad \text{(J= FC, VP, HP, CP)} \qquad (4)$$

Hence, using the indicator function, the unobserved preferences in Eq (4) translate into the observed binary outcome equation for each choice as follows:

$$Y_{ij} = \begin{cases} 1 & \text{if } \; Y_{ij}^{*} > 0 \\ 0 & \text{otherwise} \end{cases} \qquad \text{(J= FC, VP, HP, CP)} \qquad (5)$$

In multivariate probit model, where the options of several strategies of income diversification are possible, the error terms jointly follow a multivariate normal distribution (MVN) with zero conditional mean and variance normalized to unity (for identification of parameters), where $(u_{fc}, u_{pv}, u_{ph}, u_c \sim$ MNV $(0, \Omega)$ and the symmetric covariance matrix is given by:

$$\Omega = \begin{pmatrix} 1 & \rho fcpv & \rho fcph & \rho fcc \\ \rho pvfc & 1 & \rho pvph & \rho pvc \\ \rho phfc & \rho phpv & 1 & \rho phc \\ \rho cfc & \rho cpv & \rho cph & 1 \end{pmatrix} \qquad (6)$$

Where $\rho$ denotes the pairwise correlation coefficient for the error terms corresponding to any two options equations to be estimated in the model. The off-diagonal elements in the covariance matrix represent the unobserved characteristic that affects the choice of alternative options. The regression coefficients of the MVP can be interpreted using the marginal effects of change in the explanatory variable on the expected value of the dependent based on (Greene, 2002; Wooldridge, 2002). A positive correlation is interpreted as a complementary relationship, whereas a negative correlation is interpreted as being a substitute.

Seemingly Unrelated Regression (SUR) was used to determine the factors that affect the level of income generated from each of sources of farm income. SUR model presents joint estimates of several regression models, each with its error term and with zero mean, variance and covariance. The parameter estimates in the SUR model vary from equation to equation and the independent variables. The model consists of $j = 1...m$ linear regression for $i = 1...N$ individuals. The $j^{th}$ equations for individual $i$ is :

$$Y_{ij} = X_{ij}\beta_j + \varepsilon_{ij} \qquad (7)$$

For different sources of income generation, it can be written as:

$$Y_{fc\_income} = \beta_0 + \beta_1 X_1 + .... + \varepsilon_1$$

$$Y_{cat\_income} = \gamma_0 + \gamma_1 X_2 + ... + \varepsilon_2$$

$$Y_{vg\_income} = \delta_0 + \delta_1 X_3 + \ldots + \varepsilon_3 \quad (8)$$

$$Y_{h\_income} = \theta_0 + \theta_1 X_3 + \ldots + \varepsilon_4$$

Where $Y_{fc\_income}$, $Y_{cat\_income}$, $Y_{vg\_income}$ and $Y_{h\_income}$ are income from food crop production, cattle sale, vegetable production and horticultural production for income generation activities respectively.

Table 2 provides the expected sign of explanatory variables used in the models. Age is hypothesized to have either positive or negative effect on the decision to sale and the income generated from the four strategies. Land ownership is expected to have a positive influence on multiple sources of income and the amount of income that each source generates. In rural areas, a large family size implies availability of labour and, therefore, it is hypothesized to have a positive effect on the diversity of agricultural activities as well as economic proceeds from the activities. Dependency ratio is expected to have a positive influence on the number of farm enterprises and either positive or negative influence on income generated from multiple farm enterprises. Education level is an important capital for enhancing the diversity of source of income. The study expects education to positively influence the sale of produce from the four enterprises and the amount of income received by farmers.

Institutional factors such as access to agricultural credit and extension services are hypothesized to positively influence smallholder farmer income generation activities. Income from cash crop (cotton) is expected to positively influence the diversity of other farm income generating activities. Off-farm income is expected to have both negative and positive influence on income generated from the four farm enterprises. Income from off-farm activities can be invested in agriculture, contributing to diverse sources of farm income. Off-farm income, on other hand, may also discourage the sale of farm produce by influencing farmers to produce for self-consumption and not for the market. Agricultural input prices and state of rural infrastructure are expected to either have a positive or negative association with the sale of farm produce and income generated from the sale.

Table 2: Description, measurements and expected sign of variables

| Variable | Description | Expected sign |
|---|---|---|
| **Dependent variable** | | |
| Multiple sources of income generation strategies | | |
| | Food crop sale yes =1; No =0 | |
| | Vegetable production sale yes=1;No=0 | |
| | Horticulture sale yes=1;No=0 | |
| | Cattle sale yes =1; No=0 | |
| **Explanatory variable** | | |
| Land ownership | Land ownership | + |
| Education | Education level | + |
| Credit | Access to credit | + |
| Extension | Access to extension services | + |
| HcostAgrinput | Hight cost of agricultural inputs | - |
| Infrastructure | Poor infrastructure | - |
| LPagri products | Low price of agricultural products | - |
| Age | Age of family head | + /- |
| Family size | Family size | + |
| Dependrotio | Dependency ratio | +/- |
| Cash crop | Cotton income in FCFA | + |
| Off farm | Total off income in FCFA | -/+ |

### 3.3.2. Objective two

To determine the socio-economic factors influencing smallholder farmers crop diversification in Southern Mali

Econometric models such multivariate probit or logit, multinomial probit, nested logit, conditional fixed effects logit, among others are useful for analysis categorical outcomes. In the study, multinomial logit (MNL) is appropriate for analysis of categorical dependent variables when farmers must choose only one outcome from among the set of crop diversification strategies. As opposed to MNL, the above econometric models allow the possibility of simultaneous choice of dependent outcome (Greene, 2002; Wooldridge, 2002).

The choice of the MNL model was also backed by previous related studies that applied the same model in estimating the effects of socioeconomic and institutional factors on crop diversifications (Jansen *et al*., 2006; Rahut *et al*., 2014; Belay *et al.*, 2017).

Multinomial logistics (MNL) regression is an analytical method that is commonly used to analyse smallholder farmers' choices of agricultural strategies.

It allows analysis of decisions across more than two categories (Greene, 2002; Wooldridge, 2002). The MNL model is also used in assessing the choice of alternative combinations of strategies in smallholder crop and livestock production systems (Babulo *et al*., 2008; Deressa *et al*., 2009). The model is used to analyse the factors that influence smallholder farmers' decisions to diversify crop enterprises in cotton growing zone of Mali.

The Simpson Index of Diversity (SID) was used to characterize and measure the degree of diversification at smallholder farmer level (Joshi *et al.,*2003; Fabusoro *et al*., 2010; Ahmed *et al*.,2015).The measure of diversification is based on the area (hectare) of land under the main crops (cotton, maize, millet and sorghum). Livestock owned by smallholder farmers is expressed in terms of Tropical Livestock Units (TLU). The SID ranges between zero (0) and one (1) where 0 denotes specialization and 1 means extremity of diversification. The SID general formula is given as:

$$SID = 1 - \sum_{i=1}^{n} P_i^2 \qquad (9)$$

where SID denotes Simpson's Index of the Diversity, $P$ is the proportion of enterprises coming from $i^{th}$, $n$ is number of enterprises $(n = 1, 2, ...., 5)$.

Following the random utility model (RUM), we assume that smallholder farmers aim to maximize their income, $U_i$, by comparing the income generated by $j$ alternative strategies. The expected income, $U_{ij}^{*}$ that the smallholder farmer derives from engaging in strategy *j* is a latent variable determined by the observed farming family characteristics $X_i$ and unobserved $\varepsilon_{ij}$. Therefore,

$$U^{*}_{ij} = X_{ij}\beta_j + \varepsilon_{ij} \qquad (10)$$

Where $\beta_j$ is the parameter associated with $X_j$ that remains constant across alternatives and $\varepsilon_{ij}$ is a random disturbance term that capture intrinsically random choice behaviour, measurement or specification error and unobserved attributes of the alternatives.

To describe the MNL model, let $P_{ij}$ *(j=1, 2, 3, 4)* denote the probability associated with cropping activity choices of a smallholder farmer $i$ with: $j = 1$ if the smallholder farmer combines cotton plus maize, $j = 2$ if the smallholder farmer combines cotton, maize and millet, $j = 3$ if the smallholder farmer combines cotton, maize, millet and sorghum and $j = 4$ if the smallholder farmer only practices food crop production.

Following Greene (2002), the MNL model is given as:

$$P_{ij} = \frac{Exp(X_i \beta_j)}{\sum_{j=1}^{4} Exp(X_i \beta_j)} \qquad (11)$$

Given a convenient normalization that solves the indeterminacy problem inherent in Eq. (11) is $\beta_j = 0$, then MNL model can be rewritten as:

$$P_{ij} = \frac{Exp(X_i ' \beta_j)}{1 + \sum_{j=1}^{4} Exp(X_i ' \beta_j)}, \text{ j = 1,2,3,4.} \qquad (12)$$

Where $\beta_j$ is a vector of coefficients on each of the independent variables $X_i$. This can be estimated using maximum likelihood. For this study, the diversification strategies or their probabilities are described in Table 8. Unbiased and consistent parameter estimates of the MNL in Eq. (4) require the assumption of independence of irrelevant alternative (IIA) to hold. The base category or reference was cereals only for the MNL. Specifically, the IIA assumption requires that the probability of using certain diversification strategies by the smallholder farmer needs to be independent of choosing other strategies. The premise of the IIA assumption is the independent and homoscedastic disturbance terms of the basic model.

**Description of explanatory variables**

The study grouped the explanatory variables into three categories. First, family characteristics include the age, education level, family size, non-farm income and farm income. The second category of predictor variables is factor endowments which include ownership of oxen and land. Last, institutional variables include access to credit and agricultural extension services. The description of explanatory variables used in the MNL model is given below.

The description of the predictor variables and the hypothesized direction of relationship with diversification are as follows.

Age of the household head plays an important role in diversification into several enterprises since it can be used to indicate farmer's experience in different farming systems. It is expected that the age of the family head increases the probability of engaging in multiple agricultural enterprises.

Family size: Refers to the number of people working together and sharing a common pool of resources. Family size might positively influence diversification strategies in agriculture. The study hypothesizes that large family size increases the probability of smallholder farmers diversifying agricultural production systems. Large family size implies availability of labour which allows participation in multiple farm activities.

Education level of family head: Refers to the literacy level of the family head. It is considered as an important factor of agricultural diversification strategies. A family headed by a highly educated member is more likely to diversify into different agricultural enterprises owing to the available knowledge on different crop and livestock enterprises and the importance of diversification to family income and food security.

Farm and non-farm income: Indicate the financial position of smallholder farmers. We hypothesize that farm and non-farm incomes positively influence diversification because it enables farmers to have increase access to farm inputs. Increased access to inputs then enhances the level of diversification.

Oxen ownership: Livestock is an important physical asset because it represents an important source of capital for smallholder farmers. Oxen constitute an important part of agricultural systems in Southern Mali because it is the primary source of animal power. It is expected that ownership of oxen positively influence diversification into different crop production systems.

Farm size and land ownership: Land is an important factor in agricultural production and can be considered as a proxy for family wealth in Southern Mali. Possessing large sizes of arable land increases the probability of diversification into different cropping systems.

Access to agricultural inputs use: Access to farm inputs induces smallholder farmers to diversify their activities. The quantity of chemical fertilizer used per hectare is still low in Southern Mali due to the high prices. Smallholder farmers have to be members of cotton cooperatives to access important inputs.

Input prices: it is an important factor for crop diversification. It is hypothesized that high inputs prices negatively influence diversification due to liquidity constraints.

Crop pest: Crop pest is an important constraint in agricultural production. It is hypothesized that crop pests influence farmer decision to diversify. A farmer may diversify into different crops to cushion against output declines of another crop because of pest infestation.

Extension services: Extension services provide technical information and advice to farmers. It contributes to the dissemination of agricultural information, knowledge and skills, thereby enhancing the uptake of different agricultural technologies. It is expected that increased access to extension information and advice encourage diversification.

Table 3: Description of explanatory variables and expectation of sign (MNL)

| Explanatory variables | Description | Expected sign |
|---|---|---|
| Age | Age of family headed | +/- |
| Family size | Number of family members | + |
| Education | Level of formal education | + |
| Farm income | Income from all farming activities | + |
| Non-farm income | Income from all off-farm activities | + |
| Oxen (livestock) | Oxen ownership | + |
| Land size | Land size (ha) | + |
| Land ownership | Land ownership | + |
| Lagriinput | Low agricultural inputs used | - |
| priceinputs | Agricultural input prices | - |
| Crop pest | Crop pest infestation | + |
| Access to credit | Access to agricultural inputs credit | + |
| Extension services | Access to agricultural extension services | + |

### 3.3.3. Objective Three

To determine the level of technical efficiency and agricultural technology practices applied by smallholder farmers in Southern- Mali.

The stochastic frontier (SF) production function model and Data Envelopment Analysis (DEA) are the two principal tools to measure farm efficiency. Among the parametric methods, the stochastic frontier analysis (SFA) is the most commonly used to measure the efficiency of farm level mainly in developing countries. The SFA method, which estimates the parametric form of a production function with a random two-part component of error term Aigner *et al. (*1977) and Meeusen and van den Broeck (1977. The economic logic in this specification is that the production process subject to statistical noise represented by $v_i$ and technical inefficiency represented by $u_i$. The production frontier is stochastics since it varies randomly across farms due to the presence of the random error component (Coelli *et al*., 2005). Thus, the following model proposed by Aigner *et al*. (1977) and the stochastic frontier production function can be written as:

$$Y_i = f(x_i\beta) + \varepsilon_i = \exp(x_i\beta + \varepsilon_i) \qquad (13)$$

Where $\varepsilon_i$ is an error term with

$$\varepsilon_i = v_i - u_i \qquad (14)$$

Where $Y_i$ denotes the output of production of the $i-th$ farmer, ( $i = 1,2,3,....n$) $x_i$ represents a $(1\times k)$ vector of functions of inputs quantities applied by the $i-th$ farmer, $\beta$ is a $(k\times 1)$ vector of unknown parameters to be estimated and $\varepsilon_i$ is two economically distinguishable random disturbances. The errors $v_i$ are random variables assumed to be independently and identically distributed $N(0,\sigma_v{}^2)$. The component $u_i$ is assumed to be distributed independently of $v_i$ and to satisfy $u_i \geq 0$ and half normal distribution $N(0,\sigma_u{}^2)$ and non-negative variables associated with technical inefficiency in production. Following Battese and Coelli (1995), the technical efficient (TE) and technical inefficiency of the $i-th$ farmer are given as:

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{Y_i}{\exp(x_i\beta + v_i)} = \frac{\exp(x_i\beta + v_i - u_i)}{\exp(x_i\beta + v_i)} = \exp(-u_i) \qquad (15)$$

$$u_i = z_i\delta + w_i \qquad (16)$$

Where $Y_i^* = f(\exp(x_i\beta + v_i))$ is the farm-specific stochastic frontier and if $Y_i$ is equal to $Y_i^*$ then $TE_i$=1 expresses 100% efficiency. For technical inefficiency, $z_i$ is a $(1\times m)$ vector of farmer specific variables associated with technical inefficiency and $\delta$ is a $(m\times 1)$ vector of unknown parameters to be estimated, $w_i$ are random variables, defined by the normal distribution with zero mean and variance $\sigma_u{}^2$. If $u_i = 0$ indicating that the production lies on the stochastic frontier, the farmer obtains maximum achievable output given the set of inputs. If $u_i \prec 0$ suggesting that the production lies below the frontier hence farmer operates on inefficiency. The inefficiencies are estimated using a predictor that is based on the conditional expectation of $\exp(-u_i)$ (Battese and Coelli, 1995). The maximum likelihood function is expressed in terms of the variance parameters as:

$$\sigma^2 = \sigma_v^{\ 2} + \sigma_u^{\ 2} \text{ and } \gamma = \sigma_u^{\ 2} / \sigma^2 \qquad (17)$$

Where the value of $\gamma$ must lie between zero and one, with values close to one indicating that random component of inefficiency makes a significant contribution and zone indicating the deviations from the frontier are due to the noise.

**3.3.3.1.Empirical application of stochastic frontier production function model**

The stochastic frontier analysis (SFA) is used to analyse the technical efficiency (TE) in crop production systems in Southern-Mali. The SFA is commonly used in the agricultural sector of least developing countries even the developed countries in technical efficiency (Theriault and Serra, 2013). The maximum likelihood estimation is interpreted based on the estimated coefficient using elasticities of variables. The general form of the model is expressed as:

$$\ln Y = \beta_0 + \alpha \ln L + \beta_1 \ln K + \varepsilon \qquad (18)$$

In crop diversification strategies, the formula is applied to cash crop (cotton) and food crops (maize, millet, and sorghum).

<u>The empiricall form of cash crop (cotton)</u>

$$LnY_i = \beta_0 + \beta_1 \ln Area(ha) + \beta_2 \ln NPK(kg) + \beta_3 \ln Urea(kg) + \beta_4 \ln Pest(litter) + \beta_5 \ln labour + \beta_6 \ln Seed(kg) + v_i + u_i$$

Where

ln = Logarithm to base e (natural log)

$\beta_0$ = Constant or intercept

$\beta_1 - \beta_6$ = Unknown scalar parameters to be estimated as elasticity

$Y_i$ = Output of cotton in Kg

$v_i$ = Stochastic error term

$u_i$ = farmer specific characteristics related to production efficiency

Maximum likelihood estimation of Eq. provides the estimators for $\beta'_s$ and variance parameters $\sigma_u^{\ 2}$ and Lambda ($\gamma$). The model of technical inefficiency effects on stochastic frontier production function is given as follows:

$$u_i = \beta_0 + \beta_1 AgeFH + \beta_2 Fsize + \beta_3 educ + \beta_4 Credit + \beta_5 Ext + \beta_6 Lagriinput + \beta_7 Hpriceagriinput + \beta_8 Freqweed + \beta_9 FreqIn\sec t + \beta_{10} offfarmInc + \beta_{11} Plotsize(ha)$$

The study considered the farm profit which is measured in terms of Gross Margin (GM), it is equal to the difference between total revenue (TR) and total variable cost (TVC). It can be expressed as:

$$GM(\pi) = \Sigma TR - \Sigma TVC = \Sigma P_y Q - \Sigma P_x X \quad (19)$$

Table 4: Stochastic frontier production function variables and technical inefficiency

| Variables | Measurement | Expected sign |
|---|---|---|
| **Production function** | | |
| Crop yield | Kg per hectare | + |
| Land size | Hectare | + |
| labour | Man day | + |
| NPK | Kg | + |
| Urea | Kg | + |
| Pesticide | Litter | + |
| Seed | Kg | + |
| **Technical inefficiency** | | |
| Age family head | Year | - |
| Family size | Number of person | -/+ |
| Access to credit | Access to agricultural inputs credit | - |
| Extension services | Access to agricultural extension services | - |
| Education | Level of education | - |
| Off farm income | Off farm income | + |
| Plots size | Hectare | - |

Note: technical inefficiency (-) increases technical efficiency and (+) decreases TE

**3.3.3.2. Determinants of agricultural technologies practices**

**Cotton cropping agricultural technology practices**

Most of agricultural technology practices choices are expected to affect smallholder farmers livelihood in SSA. To determine the effect of agricultural technology practices in cotton growing, the binary logistic regression was applied with a dummy variable. Farmers were asked whether they applied organic matter under cotton or not. In most agricultural technology practices, the observed Yes/No decision is viewed as the outcome of the binary choice model. Therefore, each smallholder farmer's choice is indicated by the dummy variable.

$$Y_i = \begin{cases} 1 & if \;\; Y_i > 0 \\ 0 & Otherwise \end{cases} \quad (20)$$

The probability that a farmer adopt technology is denoted as $p = P[Y_i = 1]$ whereas the probability of non-adopters is $1 - p = P[Y_i = 0]$. The binary agricultural technology practices had a probability function $f(Y_i) = P^{Y_i}(-P)^{1-Y_i}$ where $Y_i = 0,1$ (Greene, 2002; Wooldridge, 2002). The logit model can be employed to estimate the probability of farmer's adoption of organic matter used and can be expressed as:

$$P_i = P[Y_i = 1] = \frac{e^{x_i\beta}}{1 + e^{x_i\beta}} \quad (21)$$

The linear specification of model is expressed a:

$$Y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} ........\beta_{ni} x_{in} \quad (22)$$

Where $Y_i$ is the dependent variable, $\beta_0$ is the constant and $\beta_{1.}......\beta_n$ are the coefficient of independent variables of $x_{i1} x_{in}$.

This provides the maximum likelihood estimates of the logit model, the marginal effect defines as the effect change of a unit change in $x_i$, all others factors help constant. It can be written as:

$$\frac{\Delta P_i}{\Delta x_i} = \frac{\partial P_i}{\partial x_i} \quad (23)$$

**Maize cropping agricultural technology practices**

Several studies related to agricultural technology use indicate that agricultural technologies are interdependent and use of a technology may influence the likelihood of practice of another technology for multivariate agricultural technology practices decision. The smallholder farmers are more likely to choose two or more strategies for improved livelihood simultaneously. In addition, the different selection of options of agricultural technology practices depends on farmer's willingness to maximize their profit and is conditional to socioeconomics, institutional and production systems. Multinomial logistic regression is appropriate when smallholder farmers can choose only one outcome from among the set of options. Correlation between the different agricultural technology practices is due to technological complementaries (positive correlation) or substitutabilities (negative correlation). Therefore, the MVP model consists of four binary choice equations which are: improved seed (is), organic matter (om), plough+ hand sowing (ph) and plough+ sowing (ps).

It is characterized by a set of $n$ binary dependent variables $Y_i$ and normally distributed stochastic errors ( $\varepsilon_{ij}$ ).

$$Y_{ij}^{*} = \beta_j X'_{ij} + \varepsilon ij \qquad (24)$$

Where $Y_{ij}$ $(J = 1,...,k)$ represent the unobserved latent variable of an option of strategies adopted by the farmer. The unobserved preferences in Eq. (23) translate into binary outcome equation for each chooses as follows:

$$Y_{ij} = \begin{cases} 1 & if\ Y^{*}_{ij} > 0 \\ 0 & Otherwise \end{cases} \qquad (25)$$

In multivariate probit model, where the options of several agricultural technology practices are possible, the error terms jointly follow a multivariate normal distribution (MVN) with zero conditional mean and variance normalized to unity (for identification of parameters), where ( $u_{is}, u_{om}, u_{ph}, u_{ps} \sim MNV(0,\Omega)$ and the symmetric covariance matrix is given by:

$$\Omega = \begin{pmatrix} 1 & \rho isom & \rho isph & \rho isps \\ \rho omis & 1 & \rho omph & \rho omps \\ \rho phis & \rho p\,\mathrm{hom} & 1 & \rho phps \\ \rho psis & \rho psom & \rho psph & 1 \end{pmatrix} \qquad (26)$$

Where $\rho$ denotes the pairwise correlation coefficient for the error terms corresponding to any two options equations to be estimated in the model. The off-diagonal elements in the covariance matrix represent the unobserved characteristic that affects the choice of alternative options. The regression coefficients of the MVP can be interpreted using the marginal effects of change in the explanatory variable on the expected value of the dependent based on (Greene, 2002b; Wooldridge, 2002).

**Millet and sorghum agricultural technology practices**

To determine factors affecting millet and sorghum agricultural practices a bivariate probit model was used. Agricultural Technology adoption is sometimes linked with multiple steps of decision making to practice plough + sowing (Ps) and inorganic fertilizer (If). The dependent variable is whether farmers practice the plough + sowing and or inorganic fertilizer. The dependent variable plough + sowing takes the value 1 if the farmer adopts the practice and 0 otherwise. Similarly, for inorganic fertilizer, the dependent variable takes the value 1 if farmer applied inorganic fertilizer and otherwise. In a bivariate probit model four possibilities are associated which are: (i) the non-practice of both practices (Ps = 0, If = 0); (ii) the practice of plough + mechanic sowing practice (Ps =1, If =0); (iii) the adoption of inorganic fertilizer practice (Ps=0, If =1) and the practice of both practices (Ps =1, If =1). The bivariate probit model is based on the joint distribution of two normally distributed variables and is specified as (Greene, 2002b):

$$Y_{1i} = \beta_1 X_{1i} + \varepsilon_{1i} \quad (27)$$

$$Y_{2i} = \beta_2 X_{2i} + \varepsilon_{2i} \quad (28)$$

$$f(Ps, If) = \frac{1}{2\pi\rho Ps\rho If\sqrt{1-\rho^2}} e^{-(\varepsilon_{Ps}{}^2 + \varepsilon_{If}{}^2 - 2\rho\varepsilon_{Ps}\varepsilon_{If})/(2(1-\rho^2))} \quad (29)$$

$$\varepsilon_{Ps} = \frac{e - \mu_{Ps}}{\rho_{Ps}} \quad (30)$$

$$\varepsilon_{If} = \frac{e - \mu_{If}}{\rho_{If}} \quad (31)$$

Where $\rho$ is the correlation between plough + sowing and inorganic fertilizer, $\sigma PsIf = \rho\sigma_{Ps}\rho_{If}, \mu_{Ps}, \mu_{If}, \rho_{Ps}$ are the covariances and $\rho_{If}$ is the mean and standard deviation of the marginal distribution of plough + mechanic sowing and inorganic fertilizer respectively.

Where $\beta_1$ and $\beta_2$ are parameters to be estimated, $X_{1i}$ and $X_{2i}$ are vectors of explanatory variables which includes farmers characteristics and institutional factors. $\varepsilon_{1i}$ and $\varepsilon_{2i}$ are normally distributed stochastic errors.

### 3.3.4. Objective four

To simulate collective decision of farming systems using *Olympe* (software) in order to understand and predict dynamics of smallholder farmer's income based on farming family typology. "*Olympe* is a Decision Support System (DSS) for farming systems (Ayadi *et al*., 2013; Le Bars *et al*., 2014). *Olympe* was developed by National Institute for Agricultural Research (INRA), Agricultural Research Centre for International Development (CIRAD) and Mediterranean Agronomic Institute of Montpellier (IAMM). It integrates both economic and technical information such as crop and livestock systems' operations (Grusse *et al*., 2006). Simulation with Olympe allows prediction of the consequences of different scenarios foreseen by farmers (Le Bars et al., 2007).

It permits working interactively with farmers either individually or as a group (farmer typologies). The software is a simulator that helps in decision making in agriculture at individual or scale levels. In this study, *Olympe* was used at scale that is farmer groups or typologies established in objective one. The software is applied to explore different scenario such as land size under cotton, subsidy of inputs and fluctuation of per unit farm gate price of cotton among others. Additionally, several scenarios are explored to understand farm income fluctuations, risks and evolution of markets.

In this study, *Olympe* was used to compare Gross Margins (GM) of the five types of farming families under different scenarios. The scenarios of this study were simulated for 10 years from 2016 to 2025 to predict the trend of GM of the five types of farming families in Southern-Mali. Cotton was the reference crop for it generates much of the farm income. Cotton opens a window of opportunities such as access to inputs and extension services. The scenarios considered in this study were:

Scenario 1: What would happen to the GM of the five farming families when the land size under cotton is increased and inputs are subsidized?

Scenario 2: What would happen to the GM of the five farming families when the land size under cotton is increased without input subsidy?

Scenario 3: What would happen to the GM of the five farming families when the land size under cotton is decreased without input subsidy?

# CHAPTER FOUR

# RESULTS AND DISCUSSION

## 4.1. Descriptive statistics in Multivariate Probit (MVP) and Seemingly Unrelated Regression (SUR)

Table 5 provides descriptive statistics of variables used in the model. Food crop sale is the sale of surplus maize, millet, and sorghum. The sale of food crops enables smallholder farmers to supplement the incomes cotton production to meet the daily family expenditure. Despite the role played by food crops in food security in Southern Mali and Mali in general, the sale of food crops is widely practiced in the cotton growing zone. About 77% of the sampled smallholder farmers sold food crops. The sale of food crops may result in food shortages before the end of the growing season which is mainly from August to September. In addition, many of smallholder farmers sell and buy staple food at high prices before the new harvest.

The sale of vegetable produce was also considered as an important alternative income-generating activity by smallholder farmers. About 32% of the smallholder farmers engaged in vegetable production and marketing. However, vegetable production is limited by lack of water. It is important to indicate that vegetables are mainly grown during the dry season when water availability is a major problem. This constitutes a major obstacle to farmer participation in the vegetable output market.

Horticulture is another source of income. About 40% of the farmers sold horticultural produce. Horticultural crops commonly grown for sale in the study area include mangoes, oranges, cashew nuts, and bananas. The produce is mainly consumed at home largely due to lack of market. Most of the horticultural producers sold their produce within the village at low prices. Therefore, the sale of horticultural produce is undertaken by smallholder farmers as a secondary income generating activity and as a strategy for income diversification.

Livestock sale is defined as the sale of cattle. Historically, herd size cattle are from cotton investment and from common pool resources. The decision to sell cattle in Southern Mali usually involves at least three family members, depending on the size of the family. About 32% of sampled farmers sold cattle annually. The sale of cattle is usually made when a family is faced with enormous social events (dowry, burial ceremony, wedding, and health), financial constraints such as the acquisition of tractor or reimbursement of agricultural credit.

**Farming family characteristics**

Family farming heterogeneity includes the age of family head (chief of the family), education level, family size and land tenure. These are relevant variables that may influence smallholder farmers to engage in several activities for income generation strategies. In the study area, all families are male-headed. The descriptive statistics Table 5 show that on average, the mean age family head was 56 years. The older family head has more experience in agricultural practices and possesses an indigenous knowledge, thus likely to undertake multiple sources income activities to improve their livelihood. Education level, also, has a positive effect on income strategies. About 51 % did not attend formal school, and 49 % of family head had formal school at primary level.

**Variables depicting factors endowment of farming family**

The well-being of families in the cotton growing zone in Mali is determined by the family size and ownership of land, cattle and agricultural equipment. On average, a smallholder farming family had 23 people living under the same roof and sharing common family resources. Landlessness in Southern Mali is associated with immigration. However, the landless had access to land. The dependency ratio measured family composition and age structure. The average household size for the sampled families was 1. On average, farmers had 1201 FCFA in total annual income from cash crop. There was high variability of cash crop income among farmers. The results also indicate that non-farm activities are important sources of income among farmers. On average, farmers earned 371,269 FCFA from non-farm income-generating activities.

Turning to the institutional variables, about 19% of farmers had access to credit to invest in small businesses and informal grain trade. Agricultural extension services are important avenues for improving farmers' engagement in agriculture. Extension agents provide advisory services, share knowledge and provide information about agricultural production. About 18% of smallholder farmers had access to extension services. About 77% of smallholder farmers indicated that input prices were high, thereby discouraging them from engaging in multiple agricultural enterprises. The survey result revealed that a majority, about 81%, of the sampled smallholder farmers realized low agricultural output prices. Lastly, infrastructure refers to the state of rural roads that link villages to the main markets. Results showed that about 40% of farmers faced challenges in accessing markets primarily due to the poor roads. Poor infrastructure (roads) may cause severe damage to perishable products as result of delayed delivery to the market.

Table 5: Descriptive statistics of the variables used in the models

| Variables | Description | Frequency | | %age |
|---|---|---|---|---|
| Dependent variables for multiple sources of income (Dummy: Yes =1; No =0) | | | | |
| Fc | cereals crops | Yes | 103 | 76.87 |
| | | No | 31 | 23.13 |
| Vp | Vegetable production | Yes | 43 | 32.09 |
| | | No | 91 | 67.91 |
| Hp | Horticulture production | Yes | 54 | 40.3 |
| | | No | 80 | 59.7 |
| Cs | Cattle sale | Yes | 43 | 32.09 |
| | | No | 91 | 67.91 |
| Independent dummy variables | | | | |
| Land ownership | | Yes | 114 | 85 |
| | | No | 20 | 15 |
| Education form | | Yes | 66 | 49.25 |
| | | No | 68 | 50.75 |
| Credit | access to credit | Yes | 26 | 19.4 |
| | | No | 108 | 80.6 |
| Extension | extension services | Yes | 18 | 13.43 |
| | | No | 116 | 86.57 |
| Hcostagri inputs | High cost agricultural inputs | Yes | 103 | 76.87 |
| | | No | 31 | 23.13 |
| Infrastructure | Poor infrastructure | Yes | 53 | 39.55 |
| | | No | 81 | 60.45 |
| L P agri products | Low price Agri products | Yes | 108 | 80.6 |
| | | No | 26 | 19.4 |
| Independent continuous variables | | | Mean | SD |
| Age | Age of family head | | 56 | 15 |
| Family size | Number of people | | 23 | 19.11 |
| Cash crop | Cotton income in FCFA | | 1201 | 1750 |
| Off-farm income | Total off income in FCFA | | 371,269 | 744503 |
| Dependency ratio | Dependency ratio | | 1 | 0.21 |

## 4.2. Descriptive statistics of explanatory variables in Multinomial logistic (MNL)

Table 6 provides the summary statistics of family characteristics, endowment and institutional variables used in the analysis. The average number of oxen owned was 4 per family. On average, the total land size under the main crops (cotton, maize, millet and sorghum) was on average 11.51 ha per farming family. Smallholder farmers practiced various non-farm activities such as informal trade, traditional gold mining, casual work, and handcraft among others. The average annual earnings from non-farm activities was about 371,269 FCFA compared to annual farm income per capita of about 33,252 FCFA.

The results showed that about 46% of farmers thought that they used enough quantities of agricultural inputs against 54% who thought otherwise. About 77% of sampled farmers reported that the price of agricultural inputs was high. This could be attributed to the tendency of the cotton company to charge interest on the inputs supplied on credit to its contracted farmers. About 53% of sampled farmers indicated that cotton and maize outputs were severely affected by pests despite interventions by the cotton company. Most of the cultivated land, about 85%, is owned by the family. About 15% of the cultivated land area is freely used (no rental fee) by immigrants and others related people. Turning to institutional factors, about 80% and 90 % of the sampled smallholder farmers expressed that they had no problem accessing extension and credit services respectively. The farmers indicated that field agents from the cotton milling company trained them on good agricultural practices and crop production.

Table 6: Descriptive statistics of variables in MNL

| Explanatory variable | Mean | S.D | | |
|---|---|---|---|---|
| Age of family headed | 56 | 15.022 | | |
| Family size | 23 | 19.112 | | |
| Oxen | 4 | 2.851 | | |
| Nonfarm income | 371269 | 744503 | | |
| Income per capita | 33252 | 30576 | | |
| Farm size (ha) | 11.51 | 8.31 | | |
| Qualitative descriptor | | | Frequency | % |
| Education | | Yes | 66 | 49 |
| | | No | 68 | 51 |
| Low inputs used | | Yes | 62 | 46 |
| | | No | 72 | 54 |
| Agricultural price inputs | | Yes | 103 | 77 |
| | | No | 31 | 23 |
| Crop pest | | Yes | 71 | 53 |
| | | No | 63 | 47 |
| Land ownership | | Yes | 114 | 85 |
| | | No | 20 | 15 |
| Access to credit | | Yes | 107 | 80 |
| | | No | 27 | 20 |
| Access to extension services | | Yes | 120 | 90 |
| | | No | 14 | 10 |

Note: the exchange rate at the time of survey was 558 FCFA (Franc of the African Financial Community) for USD1

### 4.3. Comparative descriptive statistics of the three villages

Table 7 presents descriptive statistics of mean characteristics amongst three selected villages in Southern Mali. It describes farmer's characteristics, livestock ownership (oxen and breeding cattle), agricultural equipment and land holding. The results show that age of family head and family size in the study are similar and not statistically significant amongst villages. The variable education level was statistically significant at 1% level across the three villages. The farmers of Nafegue and Beguene had high level of education than Ziguena farmers. This is attributed to the presence of primary schools in nearest town where the facilities for attending classes are available. High level of education enables farmers to diversify agricultural practices and improve their profit through better management. Higher level of education in many rural areas improve farmers agricultural production systems and the probability increases the success in innovation (Medina *et al*., 2015;Graeub *et al*., 2016;Suess-reyes and Fuetsch, 2016). On average, the number of oxen ownership is same across the villages and not statistically significant. Regarding breeding cattle, there was a statistically significant relationship at 5% level. Livestock rearing is the key component of agricultural development through animal power, organic matter production and savings.

The length of fallow which represented the number of years without cropping was significant at 1% level and decreasing from the Northern part (old basin) of cotton growing zone to the sub humid part. This decreasing effect of number of fallow years is explained by the pressure on natural resources due to expansion of land under cultivation. The zone under most pressure is the old basin (Beguene) with only two years of fallow and central (Ziguena) with three years. Lastly, the village in sub humid zone (Nafegue) has the longest period of 6 years without cropping. The number of fallow years is an important indicator in agriculture which shows the effect of human pressure on natural resources and difficulties in restoring soil fertility. Partey *et al.*(2017) argued that fallow is an important system in SSA agriculture which contributes to the increase of crop output and the improvement of soil fertility.

Regarding, agricultural equipment, such as ownership of ox plough, sower or planter and donkey cart, indicates that all farmers in cotton growing zones have a complete set of equipment. Allocated land size under cotton was statistically significant at 1% level across the villages. On average, Ziguena farmers had the higher share of cotton 7.29 ha compared to 4.14 for Nafegue and 2.83 ha for Beguene. Cotton cropping constitutes a major direct source of income and allow smallholder farmers to access agricultural inputs, credit, equipment, extension services amongst others. In addition, income from cotton is invested into livestock (cattle) as family savings. Maize size (ha) was relatively high 4.92 ha for Nafegue compared to 4.20 ha for Ziguena and 1.66 ha for Beguene. Land allocated for maize cropping was statistically significant at 1% level across the three villages. This is attributed to the role of maize in the crop rotation systems and major staple food grown in the study area.

Land size (ha) under Sorghum was not statistically significant among three villages. The results show that on average, Beguene nd Ziguena had almost a similar land size under sorghum at 1.35ha and 1.34 ha compared to Nafegue with 0.85ha respectively.

Concerning, millet cropping, the results indicate that land size allocated was statistically significant across the three villages at 1% level. On average, Beguena had a larger land size allocated for millet of 3.29 ha than the rest of two villages Nafegue and Ziguena at 1ha and 1.11 ha respectively. This can be attributed to the importance of millet amongst staple food in old basin zone, it is also sold daily for family expenditure and thrive well in low soil fertility. Abundance of arable land also determines widely the farmers level of agricultural diversification (Deininger and Byerlee, 2012; Lowder *et al*., 2016; Deininger *et al*., 2017).

The land reserve size amongst villages was significant at 1% level. On average, Nafegue had a larger land size reserve of 8.71 ha compared to 6.75 ha for Ziguena and 3.6 for Beguena, respectively. This could be due to high pressure on land in Beguene than the two villages attributed to cropping intensification and number of livestock (cattle) before the decline of herd size caused by lack of pasture.

The variable land ownership was not statistically significant across the three villages. However, land is proxy for agricultural production systems. Thus, Beguene village had higher land ownership with 93% compared to 82 % for Ziguena and 80 % for Nafegue. This implies that availability of land allows farmers to diversify their cropping systems and livestock rearing. In other words, farmers had the possibility to grow more than two or several crops at the same time in the cropping season.

Hence, growing multiple crops contributes to the reduction of over dependency on the cash crop income. Origin of family head was statistically significant at 5% level. About 98 % of farmers in Beguene are natives compared to 82% for Nafegue and 89 % for Ziguena. This indicates that majority of famers in three villages are natives which leads to better access to land.

Table 7: Comparative statistics of three villages

| Variables | Nafegue | | Ziguena | | Beguene | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Sd | Mean | Sd | Mean | Sd | F-test | p-value |
| Age FH | 56 | 13.83 | 58 | 14.93 | 54 | 16.24 | 0.86 | 0.426 |
| Family size | 23 | 15.03 | 23 | 17.89 | 23 | 23.99 | 0.00 | 0.997 |
| Education | 3 | 2.32 | 2 | 2.06 | 4 | 2.29 | 5.25 | 0.006*** |
| Oxen | 3.36 | 2.03 | 4.30 | 3.87 | 3.42 | 2.29 | 1.51 | 0.224 |
| Breeding cattle | 12 | 18.42 | 18.20 | 27.91 | 6.42 | 9.73 | 3.85 | 0.023** |
| Age of fallow | 6 | 6.66 | 3 | 4.04 | 2 | 3.52 | 7.22 | 0.001*** |
| Ox plough | 2 | 0.80 | 2 | 1.18 | 2 | 1.09 | 0.76 | 0.471 |
| Sower /Planter | 1 | 0.69 | 1 | 0.88 | 1 | 0.73 | 1.94 | 0.147 |
| Donkey cart | 1 | 0.60 | 1 | 0.58 | 1 | 0.79 | 1.24 | 0.291 |
| Cotton (ha) | 4.14 | 2.13 | 7.29 | 5.90 | 2.83 | 2.06 | 15.50 | 0.000*** |
| Maize (ha) | 4.92 | 1.97 | 4.20 | 2.99 | 1.66 | 1.01 | 28.98 | 0.000*** |
| Sorghum (ha) | 0.85 | 0.35 | 1.34 | 0.70 | 1.35 | 0.71 | 1.23 | 0.30 |
| Millet (ha) | 1 | 0 | 1.11 | 0.56 | 3.29 | 2.33 | 8.44 | 0.000*** |
| Land reserve (ha) | 8.71 | 6.87 | 6.75 | 6.78 | 3.6 | 4.93 | 7.65 | 0.000*** |
| Land ownership | %age | | %age | | | %age | Chi2 | p-value |
| Yes | 80 | | 82 | | | 93 | 3.697 | 0.157 |
| No | 20 | | 18 | | | 7 | | |
| Origin | | | | | | | | |
| Immigrant | 18 | | 11 | | | 2 | 5.878 | 0.053** |
| Native | 82 | | 89 | | | 98 | | |

Notes: **, ***, indicates significance level at 5% and 1% level respectively

**Description of dependent variables (Multinomial Logistic Regression)**

The dependent variable in the empirical estimation is the combinations of crop diversification strategies. The combinations that smallholder farmers were engaged are provided in Table 8. The smallholder farmers were grouped into four categories based on their diversification strategies. Accordingly, those who diversified into cotton and maize represented 24.63% of the sampled farmers. Cotton, maize and millet combination was practiced by 29.10% of the sampled farmers. A combination of cotton, maize, millet and sorghum was practiced by 39.55% of the sampled farmers. About 6.72% of the sampled smallholder farmers were only engaged in food crop production.

Table 8: Crop diversification strategies

| Diversification strategies | %age of farmers | Share of cotton | Share of cereals |
|---|---|---|---|
| Cotton +Maize | 24.63 | 44 | 56 |
| Cotton +2cereals | 29.10 | 50 | 50 |
| Cotton +3cereals | 39.55 | 48 | 52 |
| cereals only | 6.72 | 0 | 100 |

Note: cereals refer to (maize, millet and sorghum)

**4.4. Field location characteristics**

The average level of diversification was 0.6 implying that agricultural production systems were well diversified. Table 9 presents soil type based on farmer perceptions. Farmers reported four types of soils: clay, sand, gravels and silt. There was also a combination of soil types which was dominated by sand and silt and silt and clay. About 9% of farmers' fields are located on clay soils. This type of soil has a good potential for food and cash production. The gravel type of soil was reported by about 12% of the farmers and was ranked second after sand plus silt. The combination of two types of soils, sand plus silt, was the most dominant. About 74% of farmers' fields were reported to be composed of the combination. The rest of fields were located on sand and silt plus clay at 4% and 1% respectively. The diversity of land allocated to crops across the different types of soils indicates that field location plays an important role in the diversity of cropping systems. On average, farmers had three fields of land. This represents about 72% of total cultivated land area.

Table 9: Fields location per soil types in the study area (farmer perceptions)

| Soil types | Field1(ha) | Field2 (ha) | Field3 (ha) | % % |
|---|---|---|---|---|
| Clay | 127 | 49 | 0 | 9 |
| Gravels | 202 | 42 | 1 | 12 |
| Sand | 71 | 16 | 0 | 4 |
| Sand+ silt | 1045 | 357 | 92 | 74 |
| Silt + clay | 17 | 11 | 2 | 1 |
| Total | 1462 | 475 | 94 | 100 |

**4.5. Farming family component in Malian context**

The basic unit for the study was a farming family, where capital is a common pool resource under the management of the family head. A family in the context of the study area is composed of several households as shown in Table 10. The number of household members varies among families. In the sampled families, about 24 % of the farming families are composed of one household with an average 10 members. It represents most cases in cotton growing zone of Mali. In addition, 24 % of farming families consists of three households with an average of 19 members. Around 16% and 17% of farming families are composed of two and four households with an average of 13 and 28 members, respectively. They represent the small and middle-sized families in the cotton-growing zone, respectively. About 5% to 6 % of farming families are comprised of between five and six households with 32 and 39 members, respectively, representing the larger families. About 1% and 2 % of the farming families are composed of households ranging between 7 and 21 with about 51 to 153 members. These represent super large families in the study area. Most of the super large families are the natives and are well equipped in terms of agricultural tools and agricultural land.

Table 10: Percentage of number of household in the family

| Number farming family | Number Households | Average number of household members | % |
|---|---|---|---|
| 32 | 1 | 10 | 23.88 |
| 23 | 2 | 13 | 17.16 |
| 32 | 3 | 19 | 23.88 |
| 22 | 4 | 28 | 16.42 |
| 7 | 5 | 32 | 5.22 |
| 8 | 6 | 39 | 5.97 |
| 2 | 7 | 51 | 1.49 |
| 1 | 8 | 60 | 0.75 |
| 1 | 9 | 63 | 0.75 |
| 2 | 10 | 66 | 1.49 |
| 3 | 11 | 62 | 2.24 |
| 1 | 21 | 153 | 0.75 |
| 134 | 87 | 595 | 100 |

**4.6. Description of the farming family head**

In general, family headship in Mali is based on succession after the death of the head of family, creation of a new family after disputes or poor management of common income and new families coming into the village. Table 11 shows the results of the different drivers that determine the farming family headship and its effect. However, family headship by succession in the three villages was 30%, 31% and 39% for Ziguena, Beguene and Nafegue respectively. Relatively high %age of farming family separation is observed in Beguene by about 42 %, 37 % Ziguena and 21% Nafegue. The main driver of separation can be explained by poor management of income from cotton. For instance, the manager of the family income may use it for individual expenditure, provoking a dispute with other members of family thereby resulting in separation. Furthermore, an individual may be self-endowed, leading to division of plots and cattle which in the end affects communal work.

Results also indicate that farming family separation is common in the old basin zone due to low income from cotton and low yields from other crop enterprises. It is also a major source of decreasing income and food insecurity. Only sub-humid and intermediate zones of cotton growing areas receive immigrants at around 70 % and 30 %, respectively. Migration is majorly from the unfavourable zone (old basin) towards to the favourable zone due to human pressure on natural resources, changing rainfall patterns, low soil fertility and poor resource management. Migration into the sub-humid village is largely due to its favourable climate and less pressure on natural resources. This zone also tends to be densely populated due the high influx of people from other villages and it is characterized by livestock keepers who over exploit natural resources like water and grazing lands. This spurs conflicts amongst smallholder farmers.

Table 11: Farming family headship in the study area

| Villages | Succession (%) | Separation (%) | Immigration (%) | Chi2 | p-value |
|---|---|---|---|---|---|
| Nafegue | 39 | 21 | 70 | 12.335 | 0.015** |
| Ziguena | 30 | 37 | 30 | | |
| Beguene | 31 | 42 | 0 | | |
| Total | 100 | 100 | 100 | | |

Note: **, Significant at 5% levels

**4.7. Focus group discussions at village level**

Table 12 describes constraints facing farming families and available assets based on the focus group discussions. Land management in the rural areas in Mali is such that land belongs to the first families that come and settle in the area. The families have the custom right to use it. There are no written formal rules to distribute the land for the new people coming into the village. Traditional rules (often unwritten) do not allow families to plant trees, sinking of wells and sometimes construction of new settlements by new settlers. In order to symbolize that the land is not personal property, at the end of harvesting the occupier offers some basket of millet or maize or sorghum to the initial landowner. In the cotton growing area in Mali and everywhere, the rural lands have no titles but are well governed under local authorities. Analysis of village-level focus group discussion responses reveals numerous opportunities and constraints of the agricultural production systems. Farmers identified the declining yields (crops and livestock), lack of significant land fallowing, degradation of soil, low fertility of soil, limited pasture space and conflicts, low price of agricultural output, lack of improved seed for cereals (maize, millet and sorghum), and high cost of inorganic fertilizers as the major constraints in rural area. In addition, farmers perceived that climate change is the biggest challenge in agricultural production systems due to rainfall pattern.

As for marketing, farmers revealed that the value chain for milk, horticultural products is disorganized and resulted to low earning. However, farmers diversify their sources of income from cotton and food crops to off-farm activities in response to the constraints and challenges. Worryingly, the migrant workers to the traditional mining sector are negatively affecting labour provision to the agricultural production activities.

From a livestock point of view, feeding system constitutes the main problem in cotton belt. Pasture lands are hardly increasing to cope with the increasing herd sizes. This forms a major source of conflicts among farming families. Fodder is developed by extension service providers and research institutes. However, the uptake of fodder crops is decreasing as a result of rampant intercropping. Farmers indicated that due to extensive livestock keeping, they loss organic matter and milk. On the other hand, farmers indicated that Southern-Mali possesses an important opportunity to develop agricultural production systems. For instance, importance of herd size, diversity of crops, integration of crop and livestock, agricultural technologies, research institutions, NGOs among others.

Table 12: Major constraints facing farming families and assets in production system in Southern Mali

| Villages | Constraints | Assets |
|---|---|---|
| Old basin Beguene | Climate change, low fertility of soil, limited pasture space, degradation of natural resources, lack of animal feeds, soil acidity, low yield of all crops, soil erosion, difficulty to access improved seeds, low income, malnutrition, no tractors, food insecurity, late payment from CMDT, low yielding of livestock, high price of fertilizers and pesticides, low selling price for food crops | Importance of livestock, diversity of crops, extension services (research institute, National services, NGOs,..), integration of crops and livestock, equipment (draught tools) |
| Intermediary zone Ziguena | Climate change, low fertility of soil, degradation of natural resources, soil erosion, striga (weeds), insufficient quantities of fertilizer for cereals, disorganized value chain for mangoes, conflicts with transhumance... | Diversity of crops, importance of livestock, extension services ( research institute, NGOs, National services, ), integration of crops and livestock, importance of potatoes , equipment (draught tools and tractors), diversity of source of income |
| Sub-humid zone Nafegue | Climate change, low yielding for cereals, lack of improved seeds, conflicts with transhumance from the North, disorganized value chain for milk limited market for cashew | Diversity of crops, equipment (draught tools), availability of other cash crop ( Cashewnut) |

### 4.8. Institutional analysis at Malian Company of Textile Development (CMDT)

Cotton production is an important and well-organized value chain in Mali. This allows the poor farmers to access services and products from the company in charge of cotton. Indeed, poor smallholder farmers under vertical integration cultivate it. In 1974, CMDT owned 60 % of the shares whereas French Company for Textile Development (CFDT) held the remaining 40 %. Badiane *et al*. (2002) states that for West and Central Africa in CFA currency zone, the cotton sub-sector is under the restriction of unique company. This fact limits the provision of inputs and other services to farmers as it operates as a monopoly and monopsony. Malian cotton sector assumes main activities of cotton production such as extension services, production, and marketing. CMDT has a unique responsibility to supply cotton producers with inputs on credit until harvesting. It supplies fertilizer for cotton and maize production, seeds, pesticides, draught tools, and oxen.

It also empowers farmers on cotton production techniques through regular training and extensions services. It offers guaranteed purchasing price, transportation, and marketing (Tefft, 2004). CMDT holds monopoly power in the cotton production system. In addition, the Malian cotton sector is sustained by the collaborative effort of Institutes of research such as National Institute of Rural Economics (IER) and International Research Centre Agricultural Research Centre International Development (CIRAD). The support is based on agronomist aspects such as varietal breeding, soil fertility and bio-pesticides (Benjaminsen, 2001; Theriault *et al*., 2013). In the least developed countries, information and technologies transfer in agriculture passes through field experimentation. Although most of the smallholder farmers are uneducated, they are rich in local knowledge. Asmah (2011) argues that habitual technique of transfer of knowledge in the agricultural sector is based on trial and field school through extensional services.

### 4.9. Cotton dynamics, declining and catching up later

Cotton was produced by smallholder farmers before independence in a traditional manner. Figure 7 shows some different steps of dynamics of cotton production after the creation of CMDT. From independence in 1960 to the creation of CMDT in 1974, yield per hectare of cotton was between 225 and 731 kg/ha It corresponded with the usage of some agricultural equipment such as ploughs, seeders, and the use of unimproved cottonseed. Cotton was mainly cultivated for traditional clothing purposes, not as marketable products. During the industrial time, the total area of arable land increased from 69311 ha in 1974 to 200368 ha on average in 1994, an increase of 65 %. At the same time, yield per hectare rose from 731 kg $ha^{-1}$ to 1199 kg/ha, an average increase of about 39 %. This increase in cotton production can be explained by soil fertility, rotation system and long land fallowing. This period also corresponded to the dynamics cotton production in Southern Mali as sustained by the development of animal traction, improved fertilizer application techniques for applying fertilizers, pesticides and other techniques of cash and food crop production. The number of smallholder farmers involved in cotton production increased by 41 % between 1974 and 1994. Thus, smallholder farmers started to obtain complete draught tools (plough, seeder, donkey cart and oxen cart) and drought power. The income from cotton was invested in livestock during this period which steadily led to crop intensification and crop and livestock integration. This increased yield per hectare because of improved soil fertility and agricultural practices such as crop rotation and long land fallowing.

Second important period in cotton production zone, is at the end of 1994. The currency (CFA) diminished in its value by two, and corresponded to devaluation time and there was a decline in terms of yield per hectare despite the arable land still increasing. It dropped in 2001(producers of cotton were on strike) translated by the non-sowing of cotton. Then arable land increased in 2002 reaching 532163 ha and decreased steadily in 2009 by 196779 ha with the yield still decreasing over that period of time. The decrease corresponded to the declining period and the international crisis combined with high price of agricultural inputs: fertilizers and pesticides. Despite the entrance of a new region in Western part of country into cotton production, the yield per hectare was still decreasing. This crisis affected all agricultural sectors and particularly, the smallholder famers' income in least developing countries due to agricultural taxation and subsidy pattern. Cotton producers have since reduced the area allocated for cotton and increased food crop areas while others shifted from cotton cropping to non-farm activities or only growing food crops. That shifting is not only attributed to the deflation of price of cotton in international market but also the fluctuation of rainfall pattern and climate change.

A third important change corresponds to strengthening and catching up of cotton production because of increasing farm gate price. By 2011, the price of a kilogram of cotton was 185 CFA, and it increased to 255 CFA a kilogram in 2012. This triggered an increase in the area allocated for cotton. However, this did not translate into an increase in yield per hectare. This was attributed less subsidization of agricultural inputs such as fertilizers and pesticides. On the other hand, maize production has also increased in terms of the area allocated and yield per hectare. This has been sustained through access to fertilizer provided to cotton producers. The slowed catching up coincides with numerous factors such as climate change, low soil fertility, over cultivation and low quantity of organic matter applied. Most importantly, the population growth rate and herd size has constrained the catching up of the cotton sub-sector. This is in the backdrop of Mali being projected to be the leading producer of cotton in West Africa by 2018 (World Bank).

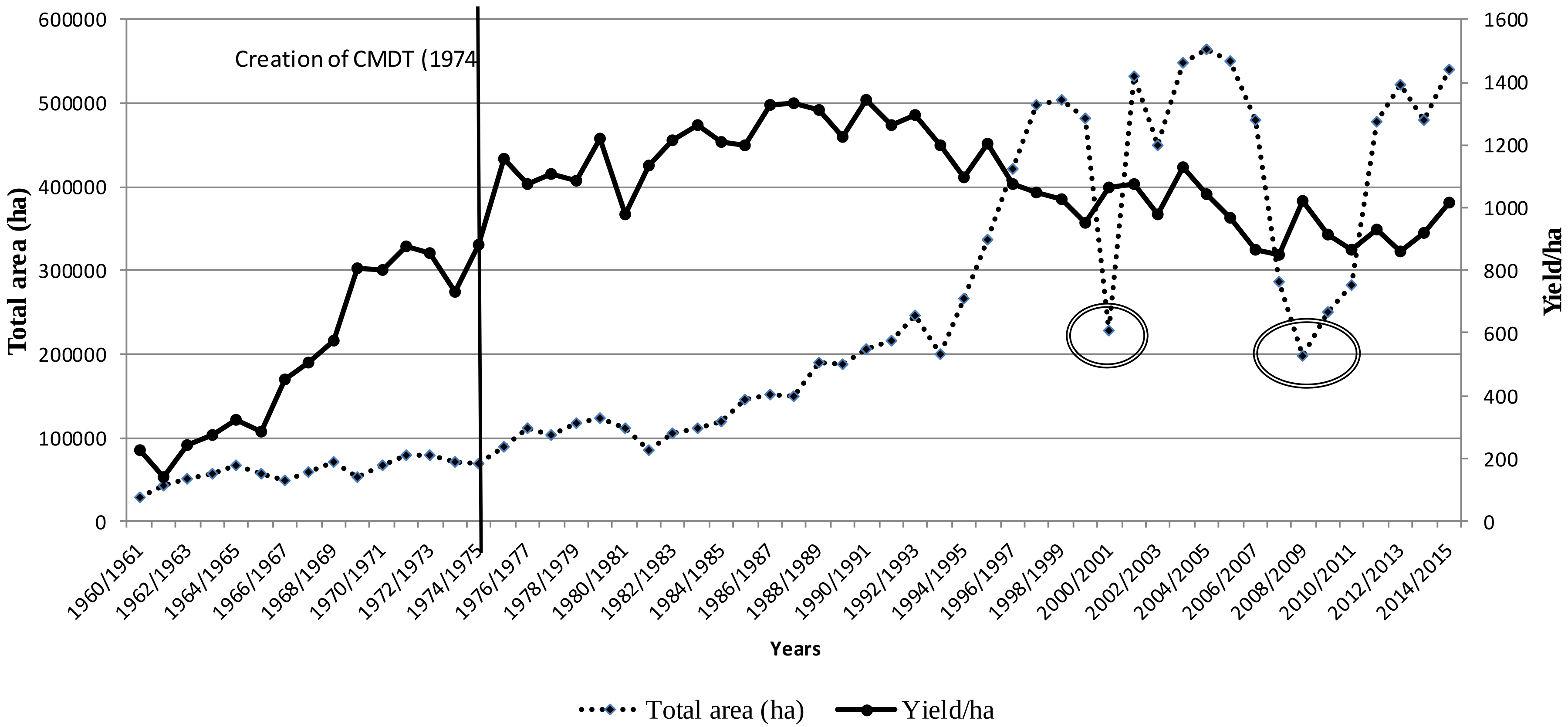


Figure 7: Evolution of cotton production from 1960-1961 to 2014-2015

Source: CMDT, 2016.

### 4.10. Dynamics of the number of farmers and area under cotton

The number of agricultural farming families involved in cotton production and the area under cotton cultivation increased between 1974 and 1994 Figure 8. In 20 years, the number of agricultural farming families has increased by 41 %. The expansion of cotton production to the western part of the country in 1995 increased the number of producers. This increased the cultivated land area under cotton by the year 2000. The number of producers and area under cotton went down due to the boycott by producers in 2001. The input prices skyrocketed as the price per kilogram of cotton plummeted. The crisis in cotton growing area started, but the number of producers still increased until the beginning of new price spikes. Afterward, both the number of agricultural farming families and area under cotton declined in 2008-2009 due to the international market crisis, high price of cotton inputs, and low farm gate price of cotton per kilogram.

These factors accompanied by severe climatic conditions in cotton growing area, worsened cotton production and marketing. Despite the crisis, the number of producers and land area under cotton cultivation went up causing further spikes. Famers cultivated cotton in order to access cotton inputs with or without subsidy and other opportunities associated with cotton production. Cotton constitutes the heart of socio-economic development and livelihood of the farming families. It is a unique and guaranteed source of income for the poor farmers and allows them to invest the surplus income in livestock and diversify sources of their livelihoods. This dependency on cotton in a closed market causes situational poverty, malnutrition and food insecurity.

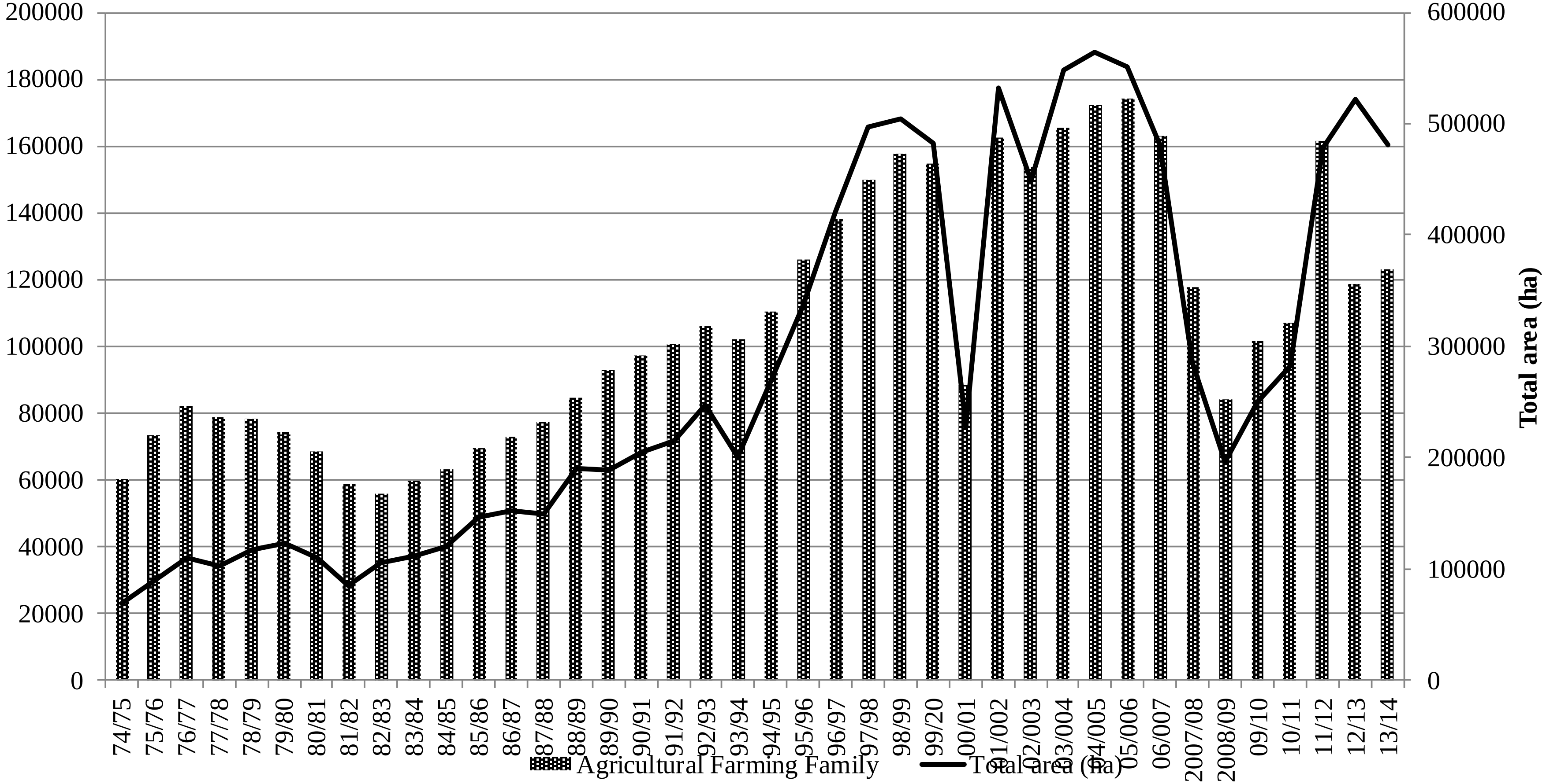


Figure 8: Evolution of number of farming families and total area (1974-2014)

Source: CMDT, 2016

## 4.11. Livestock (cattle) in the agricultural production system

### 4.11.1. Nafegue (sub humid zone)

Livestock is the heart of agricultural growth in the cotton production belt. The perceptions of agricultural farming families were analysed based on the main functions of livestock in cotton belt. The functions are shown in Figure 9. About 67% of the farmers identified draught power as the main function of livestock (cattle). Possessing oxen allows farmers to access credit and insurance as well as to plough early at the onset of rains, which guarantees food security. Farmers in Nafegue have limited access to tractor power, indicating less use fuel-powered machinery among smallholder farmers. The second function of livestock keeping in Nafegue village is milk production as indicated by 18% of the respondents. Milk production is not well developed due to information access and market. Although it offers important protein and reduces malnutrition in rural area, the milk production system is still considered non-value added. Another function of livestock keeping is organic matter production and revenue generation at 9 and 6%, respectively. These functions are considered not directly important in rural area. However, selling one head of cattle involves many members of the farming family in decision-making. Organic matter production depends on family organization and is motivated by the need to produce a large quantity and reduce the quantity of chemical fertilizer applied on the farm.

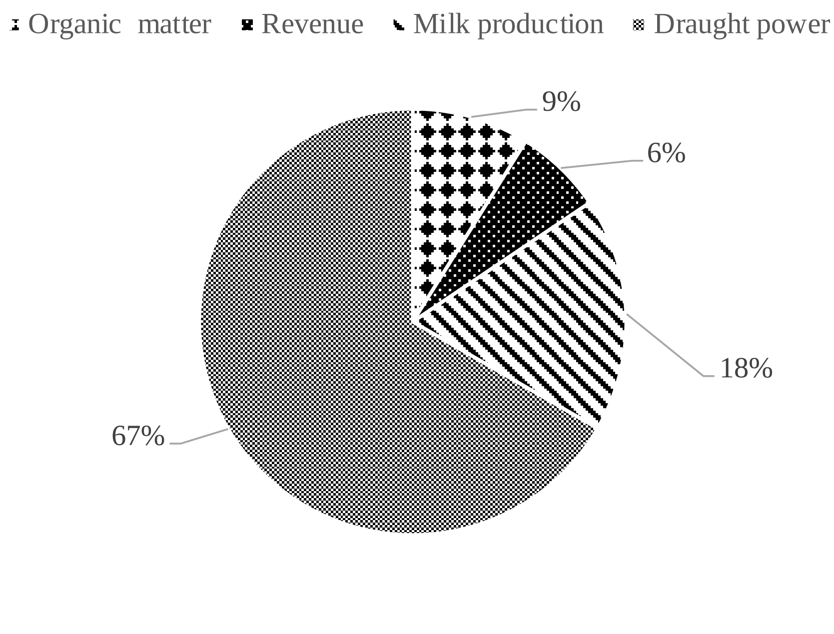


Figure 9: Objective of livestock (cattle) keeping in Nafegue

#### 4.11.2. Ziguena (Intermediary zone)

Farmers' point of view on livestock (cattle) keeping shows that drought power also constitutes the most important function at 64 % as shown in Figure 10. Having drought power in Southern Mali indicates the priority in having a large herd size. It also means being self-sufficient in terms of labour, income, organic matter, among others. Draught power allows farmers to increase farm sizes under cultivation and invest crop income in cows or bulls. On the other hand, about 18% of farmers pointed out that they keep livestock for milk production purposes. Despite the numerous interventions in milk value chain by researchers, extension service providers, and NGOs, farmers' uptake of cattle keeping for dairy purposes is still low in the cotton production belt. In other words, livestock keeping is not aimed at milk production despite milk forming part of families' daily sources of income and proteins. This observation is a confirmation of the low consumption of milk in many rural areas in Southern Mali. The last two parameters, revenue and organic matter, were rated at 14% and 4% respectively by farmers as being important pillars for livestock keeping. These findings reiterate animal power as the main function of livestock keeping in cotton growing areas in Southern Mali since mechanical equipment are not accessible or affordable to the poor farmers.

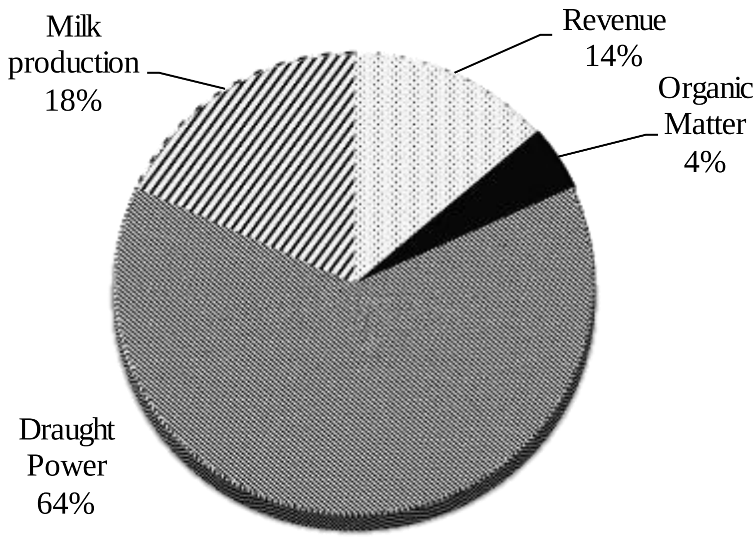


Figure 10: Objective of livestock (cattle) keeping in Ziguena

#### 4.11.3. Beguene (Old basin zone)

The old basin zone was the first cotton growing area that extensively used draught power in agricultural production system as presented in Figure 11. About 71 % of the agricultural farming families surveyed relies on draught power to improve their livelihoods. Currently, that zone is characterized by intense human pressure, degradation of environment and reduction of pasture space. Due to over-cultivation of arable land, yield per hectare for almost all crops is gradually going down. The adverse climate condition further exacerbates poor crop performance. The old basin zone is always under threat of food insecurity, malnutrition and poverty. Farmers keep draught power at home and the rest of the herd migrates towards a favourable area for feeding. Livestock migration affects milk and organic matter production. The second function of livestock keeping in Beguene village from farmers' point of view is the revenue generation. Oxen are often sold to cater for any family or social events. Milk and organic matter production were ranked as the third and fourth important livestock functions at 7 and 4%; respectively. The migration of important part of livestock for six or seven months negatively influences the quantity of organic matter produced and the quantity of milk that is produced, consumed and sold. Furthermore, the milk value chain is not well developed due to low investment and lack of market information. Milk is considered as a non-marketable commodity, which discourages specialization in milk production. Lastly, milk production in Beguene is also constrained by unavailability of improved fodder available. These occur against the background of the cotton belt being renowned for practicing crop and livestock integration and intensification.

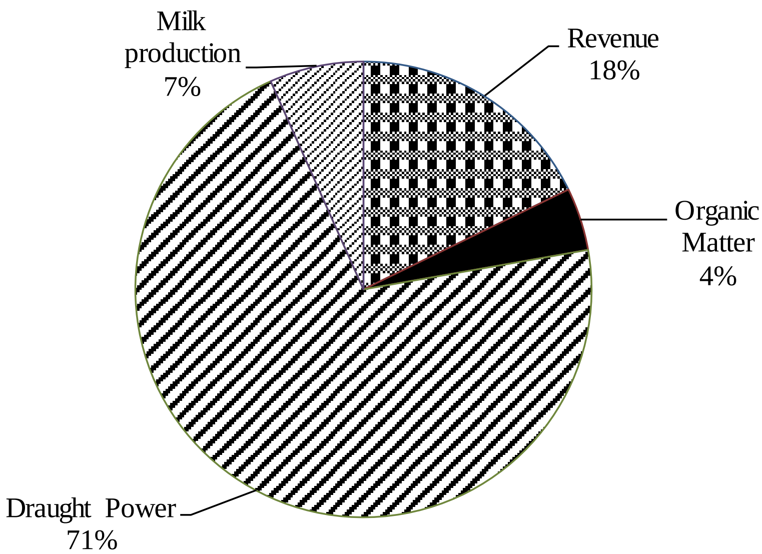


Figure 11: Objective of livestock (cattle) keeping in Beguene

## 4.12. Ascending Hierarchical Classification (AHC)

The first three proper values explain about 72.96 % of the variation in the structure of information. Other proper values (variables) contribute limited information. To define the different homogenous groups or cluster of smallholder farmers, we used AHC estimator in R analytical software Figure 12. Automatically, 134 agricultural farming families form the homogenous class or type according to their characteristics. Visual examination of the branches of dendrogram allows cutting off the place chosen based on the functioning of most homogenous smallholder farmers. This typology represents the diversity and dynamics of the sampled agricultural farming families. Thus, we chose five classes or groups for this research to describe the dynamics based on structured variables. We then compared the topology to the current typology used by researchers, CMDT and NGOs in Southern Mali.

**Agricultural farming family dynamics**

Structured and functional variables describing smallholder farmers' dynamics were classified using the Principal Component Analysis (PCA). Five classes or types were identified and are provided in Table 13

.

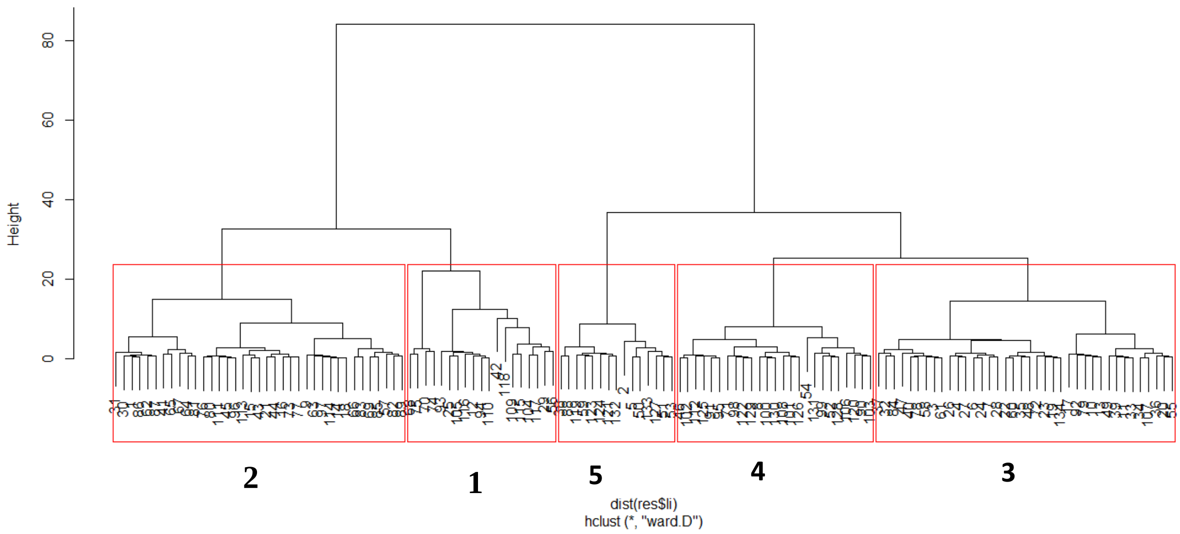


Figure 12: Dendrogram of Ascending Hierarchical classification

**Type 1: Super large families (n= 19)**

It represents 14 % of the sampled agricultural farming families. These types of families are found in all the three villages. This type corresponds to old families that invest the surplus of cotton income in livestock and farm equipment. The number of mouths to feed in such families is averagely 54 people. The average total land area under cultivation is around 26 ha and the draught tools (plough, seeder, donkey, ox cart, among others) are an average of 9 types of tools. Livestock, an important asset for crop intensification, is owned by 55 % of agricultural farming families. Approximately, 33% and 49% of the total cultivated land areas is under cotton and food crop production, respectively. Despite the importance of cotton in terms of income and supporting others crops, super large families prefer food crops in order to reduce their dependency of food purchases. However, the quantity of organic matter (manure, compost and domestic waste) applied is only 1835 kg/ha under cotton, which is a very low quantity with reference to the number of livestock, availability of labour, and draught tools owned. The super large families have a large labour force mainly composed of children and older people. These types of families also practice crop diversification, within the rainy season. Rice, groundnuts and potatoes being the most preferred crops grown in order to diversify their income sources.

**Type 2: Large families (n=37)**

About 68% of the sampled farming families are classified as large families. These types of farming families have an average of 26 people. On average, these types of families allocate about 44% and 39% of the total cultivated land areas to cotton and of food crops respectively. Large families practice cash crop farming in order to support the families' daily expenditure. In terms of age, it is similar to the type 1 but different in terms of composition. Large families are presently the most dominant type of agricultural farming families in Southern Mali. This type of agricultural families usually increases the share of land under cash crop in response to increases in farm gate prices and input subsidies. Furthermore, large families are well endowed with arable land. On average, large families cultivate 19 ha, which is 7 ha less than the super large families. About 26 % of the large agricultural families keep livestock compared to 55 % of the super large families. The quantity of organic matter applied is low at about 1062kg/ha despite the availability of technology for making organic matter and important assets such as draught tools, labour, and livestock. Despite the number of livestock owned and the productive resource endowment, large families are less specialized in intensive milk and meat production.

**Type3: Medium families (n =38)**

Type 3 is characterized by a medium number of people. This type has an average of 16 mouths to feed. About 28 % of the sampled agricultural farming families are medium-sized. Medium-sized families are also equipped in terms of draught tools and total cultivated land areas. Averagely, a medium-sized family cultivates 12 ha of land. The main feature that distinguishes medium families from large families is the number of people, livestock owned, the area allocated to food crops and quantity of organic matter applied per hectare. The share of land allocated to cotton is about 35 % of the total arable area. Cotton production is the primary activity and the principle source of income for this type of farming family.

Income from cotton is invested in livestock such as draught animal and breeding cows. The food security status of this type of families is an important driving force of the size of land that is allocated to cotton and food crop enterprise. However, it is not a primary feature that distinguishes it from type 2 families. Moreover, all agricultural farming families possess an almost identical ratio of labour except type 5. The ratio of oxen per hectare is identical for all types. Notably, farmers in Southern Mali use draught animal power for agricultural tasks. The quantity of organic matter applied per hectare by medium families is low, yet the equipment they possess is sufficient to produce an important quantity of organic matter coupled with technologies available.

**Type 4: Small families (n= 25)**

It represents 19 % of sampled agricultural farming families. This type is composed of an average of 12 people. It is considered as a small family in Southern Mali. This type can be distinguished from the first three types based on the land area allocated to food crops and the quantity of organic matter applied per hectare. Small families allocate 25 % of their arable land to cash crop in order to benefit from advantages of cash crop production such as the provision of fertilizer for cereals and access to equipment from the cotton company. Furthermore, they direct much effort to produce significant quantities of organic matter, averagely 2138 kg/ha, in order to compensate for the low quantities of chemical fertilizer offered by the company. About 56 % of small families produce important and staple food crops such as maize, sorghum and millet. This type of farming family prioritizes food security and the surplus food crops are sold and used to meet the daily expenditure. They are well equipped compared to the first typology as established by IER and CMDT. This type of farming families owns an average of 7 hectares of land and 4 draught tools. They possess a few head of cattle mainly composed of oxen for drought power

**Type 5 Young and small families (n = 15)**

It represents 11 % of the sampled agricultural farming families. It is the youngest type of families in terms of age and not the cropping system. This type has many different features or characteristics from others types. The major differences are in terms of the number of people, draught tools, livestock owned, the quantity of organic matter and area allocated to cash crops. This type of agricultural farming families is oriented towards ensuring food security. Hence, 76 % of arable land is allocated to food crops. About 11 % of the owned land areas is rotationally allocated to the cash crop. These families underutilize draught tools operating on incomplete draught tools for agricultural tasks. The ratio of workers per hectare is quite high than the others four types. The total arable land cultivated is an average of 4 hectares. The quantity of organic matter produced is very low because of lack of tools for transporting manure and harvesting the waste. Young families cultivate cash crop in order to access small quantities of chemical fertilizers which are diverted and used on food crops, particularly maize. Most of the young families detach from the extended family because of issues associated with management of common pool resources and migration of new families into others villages.

Table 13: Characteristics of farming family in the typology

| **Variables** | **Units** | **Type1** S. large Families (n= 19) | | **Type 2** L. Families, (n=37) | | **Type3** M. Families (n=38) | | **Type4** S. Families (n= 25) | | **Type5** Y. Families (n= 15) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | STDEV | Mean | STDEV | Mean | STDEV | Mean | STDEV | Mean | STDEV |
| Age | Year | 68 | 15 | 63 | 14 | 50 | 11 | 55 | 15 | 43 | 9 |
| Pop. | Person | 54 | 30 | 26 | 9 | 16 | 8 | 12 | 3 | 8 | 4 |
| Tools | No. | 9 | 2 | 7 | 2 | 5 | 2 | 4 | 2 | 1 | 1 |
| Farm size | Ha | 26 | 13 | 19 | 7 | 12 | 4.02 | 7 | 3 | 4 | 2 |
| Workers/ha | W/ha | 1.38 | 0.58 | 0.88 | 0.25 | 0.99 | 0.43 | 0.92 | 0.33 | 1.48 | 0.57 |
| Cotton % | % | 33 | 0.16 | 44 | 0.10 | 35 | 0.08 | 25 | 0.10 | 11 | 0.13 |
| F. crops % | % | 49 | 0.13 | 39 | 0.08 | 44 | 0.09 | 56 | 0.09 | 76 | 0.15 |
| Total TLU | TLU | 52 | 38.71 | 24 | 13.82 | 7.02 | 6.32 | 6.54 | 4.30 | 4 | 7.14 |
| Org Matter | Kg | 1835 | 1565 | 1062 | 538 | 790 | 402 | 2138 | 851 | 772 | 585 |
| Oxen/ha | Ox/ha | 0.31 | 0.12 | 0.27 | 0.08 | 0.26 | 0.25 | 0.28 | 0.18 | 0.32 | 0.50 |

TLU= Tropical Livestock Unit of 250 kg; ha= Hectare; kg= Kilogram; No.= Total number of equipment; W/ha= worker per hectare; F. crops= cereals crops (maize, millet and sorghum)

In this study, agricultural farming families have been classified into five types based on ten explanatory variables. Results of this study reveal that differences in farmer dynamics are largely because of difference between the typology established by IER and CMDT as illustrated in Table 1 and the newly proposal topology as illustrated in Table 3. Only the type 5 is still operating on incomplete draught tools and it represents 11 % of sampled farming families.

The new classification is largely different from the ancient CMDT type in terms of drought tools, the number of livestock owned as expressed in Tropical Livestock Unit, total cultivated land area, family size and more other factors. Tittonell *et al*. (2010) and Tittonell (2013) reported that types of farmers varied in terms of resources endowment such as land, livestock, equipment and labour. Others researchers sought to classify smallholder farmers according to the income generated from agricultural activities (Djouara *et al*., 2006; Nubukpo and Keita, 2006; Koutou *et al*., 2015). Mbetid-bessane *et al*.(2003) classified smallholder farmers in the cotton production system based on the structure and functioning of their integrated farm systems in order to understand their trajectory. Sakana *et al*. (2012) also established smallholder farmers typology in wetland zones in Kenya and Tanzania based on their production systems. Douxchamps *et al*. (2016), described and classified smallholder farmers into different groups based on their agricultural technology adoption patterns and food security in three Western African countries. The quantity of organic matter applied on crops by smallholder farmers varies between 772 to 2138 kg/ha in this study. Blanchard (2010) and Falconnier *et al.* (2016) reported that almost the same quantities, 1600 to 2500 kg/ha, as being applied in the old basin. The variability in the quantity of organic matter application can be explained by non-standardized estimation of the weight of a cartload of organic matter. In another study conducted in Uganda, Okoboi and Barungi (2012) observed that the variability in the use of organic matter and chemical fertilizer could be explained by the several constraints such as access to agricultural inputs and market information that smallholder farmer face. Vall *et al*. (2006) also argued that organic matter applied on cotton by smallholder farmers in cotton growing zone of Burkina Faso varied widely from one type of smallholder farmer another. However, from the current study, the applied quantities of organic matter war far below the recommended quantity of 5000 kg/ha. Organic matter is specifically important for reclaiming and improving soil fertility of over-cultivated land. According to Rufino *et al*. (2007) and Giller *et al*.(2010), the use of organic matter is critical in improving crops yields per land area in SSA. For this reason, farming families with an important herd size should not only produce significant quantities of organic matter but also utilize it for crop production. Furthermore, the share of cash crop in the rotation varied among farming family types.

Agricultural farming family types 1, type 2 and type 3 allocated 33, 35 and 44 % of the cultivated land area on cotton in the crop rotation system respectively. A study conducted Mujeyi (2013) in Zimbabwe showed a similar trend, where farmers allocated almost 34 % of the total cultivated land to cotton. Djouara *et al*. (2006) also found about 42 % and 30 % of the cultivated land were allocated to cotton by large and medium families respectively in Southern Mali. Small families in the cotton belt engage in cotton production in order to benefit from chemical fertilizer supply from CMDT. However, increase in the area allocated to cotton by the five types farming families may be linked to population growth and market orientation due to increases in farm gate prices. Daloglu *et al*. (2014) explained that farm typology is essential in making decision in a diverse production system. Dynamics in agricultural farming families and the diverse production systems offer multiple options for agricultural development in Sub-Saharan Africa (SSA).

**4.13 Crop and livestock in an integrated production system**

Crop and livestock production are major activities and sources of income in rural areas of least developed countries. There is limited use of farm machinery and therefore, smallholder farmers rely on animal power to expand their farm size as they attempt to maximize farm profit. In addition, integrating crop and livestock enterprise areas offers higher income to smallholder farmers as compared to those who own isolated crop or livestock enterprises (Bakhsh *et al*., 2014). Moreover, livestock is an important asset for smallholder farmers because it is used to perform different farm or cropping operations. Animal power in the cotton growing zones is a major driver of food security and plays an important role in poverty alleviation.

Figure 13 shows that agricultural farming families rear cattle for drought power. Moreover, drought power is related to herd size and quantity of manure produced. Randolph *et al*. (2014) argued that livestock rearing is essential in improving human health status by ensuring dietary diversity for both young and older household members. Other functions are also potential in certain cases or countries where animal power plays a little or feeble value addition on income. Smallholder farmers do not consider milk production and organic matter as the main objective for livestock keeping in SSA.

Although smallholder farmers integrate crop and livestock, such production systems are not sufficient in technical and economic terms because only two products, that is milk and manure, are produced (Okoruwa *et al*., 1996; Schiere *et al*., 2002). Although farming families generate revenue by selling old oxen and cows, a large proportion of the revenue is used to renew the herd, leaving little for family food and non-food expenditure The surplus is invested in new draught tools and transportation equipment and also spent on marriages, payment of caretaker, taxes and human health ( Barrett, 1991; Ba *et al*.,2011). This is as opposed to the economic and nutritional roles of milk and organic matter production in other areas in SSA. For instance, smallholder farmers in Western Kenya keep livestock with a purpose of milk production, meeting household daily nutritional requirement, and contributing to households' economic well-being (Rufino *et al*., 2007). Herrero *et al*.(2009), argued that there are many functions of livestock keeping. They encompass employment, nutrition and traction. The last function is the main objective for livestock keeping in SSA. Livestock keepings allow farmers to expand cultivated land area and reduce timing for work. Agricultural farming families are diverse and complex to understand base on their practices. Livestock rearing (cattle), being the heart of agricultural development in Southern Mali should be continuously promoted and supported.

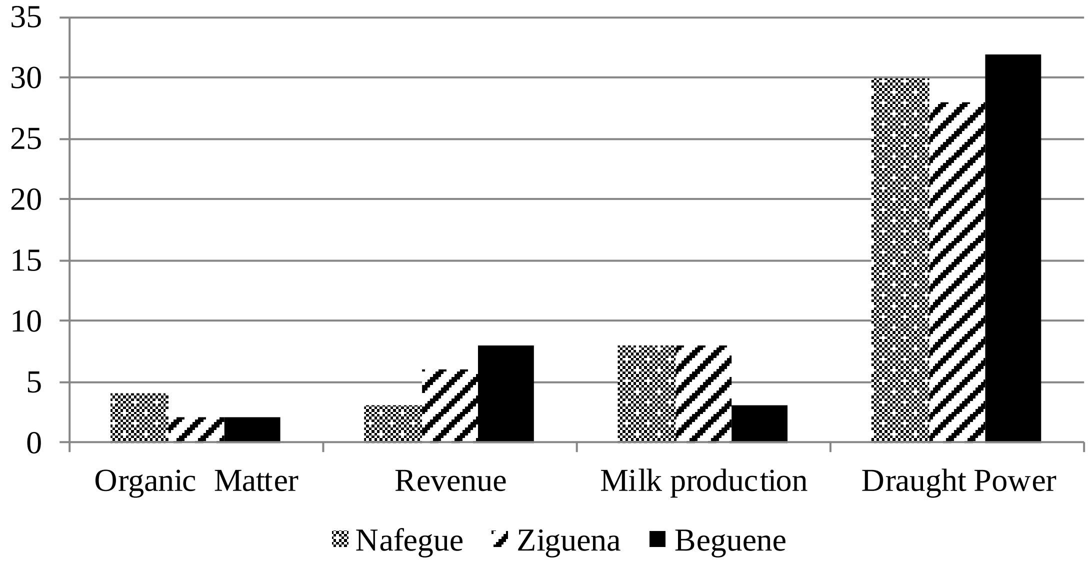


Figure 13: Main function of livestock (cattle) keeping by village

## 4.14. Econometric results of multiple sources of income

### 4.14.1. Multivariate probit regression (MVP)

The result in Table 14 shows that there are differences in income generation strategies among smallholder farmers and which were demonstrated by the likelihood test ratio of the estimated correlation matrix. Therefore, the $\rho$ values show the degree of correlation between each pairwise of dependent variables. The $\rho_3$ correlation between cattle sale and vegetable sale and $\rho_4$ correlation cereals sale, vegetable sale and horticulture sale. They are positively and negatively interdependent and significant at 1% and 5 % levels of probability. This finding indicates that farmers who generate income from cattle sale $\rho_3$ are less likely to generate income from the vegetable sale $\rho_2$. Similarly, farmers who have undertaken horticulture are more likely to multiply their income from cereals sale $\rho_1$ and less likely to participate in vegetable sale $\rho_2$.

The simulated maximum likelihood (SML) estimation of dependent variables in the model indicates that the probability of income generation strategies that farmers undertook such as cattle sale, horticulture, and cereals sale were 30; 46 and 82 % respectively. The probability of farmers selling cereals is quite high (82%) as compared to cattle sellers and horticulture sellers. The joint probabilities of success or failure of multiple source of income shows that farmers are less or more likely to multiple their income from different agricultural sources. The likelihood of farmers to diversify into several incomes source or not are around 6 % and 9 % for success and failure respectively.

Table 14: Correlation matrix of different sources of income (MVP)

| Variables | cereals sale | Vegetable sale | Cattle sale | Horticulture |
|---|---|---|---|---|
| $\rho_1$ | 1 | 2 | 3 | 4 |
| $\rho_2$ | -0.180 (0.237) | | | |
| $\rho_3$ | 0.138(0.271) | -0.502 (0.031)** | | |
| $\rho_4$ | 0.360(0.010) *** | -0.340 (0.021)** | -0.064(0.698) | 1 |
| Predicted probability | 0.82 | -1.02 | -0.70 | -0.54 |
| Joint probability (success) | 0.06 | | | |
| Joint probability(failure) | 0.09 | | | |

Note:**, ***, significant at 5% and 1% level respectively and the figures in the parenthesis are standard errors

Based on the result of likelihood ratio test in the model (LR $\chi^2$(6) =19.438, p=0.004), which indicates the null hypothesis that the interdependence between income generation strategies decision (hypothesis of zero correlation) of the error terms was rejected. This result is also supported by the significant coefficients of some of the pairwise correlation of error terms Table 14. The significant value of The Wald test ( $\chi^2$(48) =139.12, p=0.000)) is significant at 1 % level of probability and allows us to reject the conjoint nullity of variable coefficients included in the estimation. Thus, the MVP model fits the data reasonably well. These results also show the complementary (positive) relationship and or negative correlation amongst diverse sources of income generation strategies decision.

Table 15 provides results from the MVP model. The results indicate that some of the variables were significant at more than one source of income whereas other variables were significant in only one source income generation strategy. For cereals sale any of explanatory variables were not significant. All explanatory variables included in the model were significant and affected one of dependent variable. Therefore, out of twelve independent variables eight were significant at vegetable sale, four variables influenced cattle sale and three variables influenced horticulture sale in the study area at different probability levels.

The coefficient of age of family head or the chief of the family had a positive and significant relationship with the sale of cattle at 5% significance level. Older farmers are more likely to be experienced in the management of family resources than younger farmers. Age increases the capacity farmers to manage and have control over livestock income. It also increases individual autonomy in rural family setups. Hence, older farmers tend to have a greater influence in cattle marketing decisions. In addition, older persons are more informed and knowledgeable of important needs, thereby likely to identify cattle as a source of income to finances the expenditure on the needs. This finding is in line with the study conducted by Marandure *et al.*(2016) who found out that old farmers seek to emphasize the social role of cattle and more risk averse than their counterpart young farmers.

Family size was positively and significantly associated with the sale of cattle at 5% significance level. This indicates that family size in rural areas determines the probability of selling cattle in cotton growing zone of Mali. Families with many members were more likely to sell cattle in order to meet their expenditure. The sale of cattle is possibly intended to support large per capita expenditure. For instance, large families have large auto-consumption expenses on health, food, dowry and education. In other words, income from cash crop is insufficient in covering family expenditure, compelling farmers to sell cattle. This finding is in agreement with Morris *et al*. (2017) who reported that income diversification strategies plays an important role of family structure and social context.

Land ownership had a positive and statistically significant influence on the sale of vegetable and cattle at 10% significance level. The direction of the relationship between sale of vegetable and cattle and landholding is not surprising because land is an important productive resource which influences agricultural productivity. Farmers who own land possible produced more vegetable and cattle which influenced the decision to sale. Land ownership motivates farmers to allocate more land to vegetable and cattle production which, in turn, results in increased productivity. Increased productivity of vegetable is an important push factor that motivates farming families to participate in the output market.

Dependency ratio was positively and significantly associated with the sale vegetable at 10% significance level. Smallholder farmers with high number of dependents were more likely to participate in vegetable production and selling. High dependency ratio suggests that the economically active family members are burdened by high family expenditure, resulting in depressed per capita consumption. Consequently, families may resort to sell vegetables as they seek to improve per capita consumption. The sale is also possibly made to ease the economic burden on the economically active members. This finding is inconsistent with Randela *et al*. (2008) who reported that dependency ratio reduced the level of farmer participation in output market in the family reduced.

Access to credit by smallholder farmers was positively associated with the sale of vegetable at 1% significance level. The regression coefficient suggests that farmers who had access to farm credit were likely to sell vegetables. In other words, access to credit facilitated agricultural production and marketing of vegetables. Credit improves the economic power of farmers, enabling them to acquire critical inputs for increased vegetable production. This indicates that credit ensures higher market participation by farmers since it incentivizes farmers to produce vegetables beyond consumption to enable them offset the cost of credit and gain additional income. Farmers who had access to credit were possibly able to produce marketable vegetable surpluses. This is consistent with (Maertens *et al*., 2012).

Access to extension services negatively and significantly influenced the decision to sell vegetable at 1% level of probability. This indicates that farmers were not adequately persuaded to sell vegetables by receiving extension information about vegetable production and marketing. Possibly, extension information negatively influenced farmers' perception of producing vegetables for the market. This is contrary to the a priori expectation that extension services encourage farmer participation in output market. The possible explanation for this unexpected outcome is that probably extension agents emphasized achievement of dietary diversity and alleviating malnutrition when providing information about vegetable production. This finding is inconsistent with Abate *et al*. (2015); Ahmed *et al.* (2017) and Tarekegn *et al*. (2017) who reported that extension contacts positively influence farmer participation in output market.

Cash crop income was positively and significantly associated with sale of vegetable at 5% levels of probability. This is not surprising since farmers who generate more income from cash crop are more likely to invest in other farm enterprises. Additionally, cash crop farmers may allocate labour to vegetable production during the dry season. In turn, farmers sell vegetables to smooth consumption against income shock that may result from unavailability of cash crop income. In this context, multiplication of income sources is important in complementing the main source of income. Farmers may also seek to produce and market vegetables because of fluctuations of cotton output and prices and climatic conditions.

Off-farm income negatively and significantly influenced the sale of vegetable. This implies that farmer who participated in non-farm activities were less likely to sell vegetables. Off-farm income directly supports the survival of farming family. Therefore, farmers are less motivated to sell vegetables. In addition, they engage in small business, informal trade, wage labour and traditional gold mining during the dry season. Therefore, income generated from these activities may adequately complement cash crop income, preventing farmers from selling vegetables. Additionally, off-farm income creates new sources of family income which is not related to main sources of livelihood in rural areas. This is in line with Omiti and Mccullough (2009) and Rios *et al*. (2008) who argued that with higher income from off-farm discourage farmers from farming and lead to low market participation.

Education level had a positive and significant relationship with the sale of cattle at 5% level of probability. Farmers who had primary and other level of educated are more likely to be informed about output markets. Higher education enables farmers to reduce transaction cost and to possess better bargaining power. Education affords farming families with better knowledge of cattle production and marketing. Hence, knowledge and information on existing market opportunities influences farmers to focus on market-oriented cattle production. This finding is in line with Okoye *et al*. (2016) and (Seng, 2016) who argued that farmers with higher education level are able to modify production systems to opt for innovation technologies and market rules. In contrast to its effect on cattle sale, education negatively influenced the probability of farmers selling horticultural products. Horticultural commodities in Southern Mali bring low market prices. Hence, educated farmers have less focus on low return horticultural crops. In addition, the level of education in the study area is low and, therefore, farmers are less likely to seek more information on horticultural production and marketing. This is consistent with Abdullah *et al*. (2017) who indicated that farmers with low education  participate less in multiple sources of income.

Higher cost of agricultural inputs had a positive and significant relationship with the sale of horticultural commodities at 5% level of probability. High input prices reduce farmer access to important inputs for horticultural production. Low access to inputs results in low productivity which translates in low participation in the output markets.

Infrastructure had a positive and significant relationship with the sale of vegetable at 1% level of probability. This implies that with good infrastructural network (roads), farmers are more likely to participate in the marketing of vegetable products. Good infrastructural network tends to decrease the transaction costs, hence increasing the quantity of agricultural products supplied to the market. This finding corroborates the results by Abro (2012) and Sebatta *et al*. (2014) who indicated that poor road network increases transaction cost for delivering goods, thereby limiting farmer's participation in the market outlet. However, infrastructure was negatively and significantly associated with the sale of horticultural commodities at 5% level of probability. This implies that that poor infrastructure reduces farmer's participation in horticultural output market. Poor road network reduces the level of economic activities since it disconnects farmers from market opportunities. This finding is in agreement with a previous studies conducted in the Great Lakes countries of Burundi, Rwanda and Democratic Republic of Congo (Jagwe *et al*., 2010).

Market price for agricultural output had negative and significant relationship with the sale of vegetable at 5% level of probability. This is expected since low agricultural output prices discourage farmers in participating production and marketing of agricultural commodities. Low output prices represent low returns on investment in agricultural production. Farmers are less incentivized to produce and sale when the output attracts low prices.

Table 15: Multivariate probit (MVP) estimates of multiple sources of agricultural income

| | Cereals sale | | Vegetable sale | | Cattle sale | | Horticulture sale | |
|---|---|---|---|---|---|---|---|---|
| | Coef. | SE | Coef. | SE | Coef. | SE | Coef. | SE |
| Age HF | 0.006 | 0.009 | 0.001 | 0.011 | 0.020 | 0.010** | 0.006 | 0.008 |
| Family size | -0.008 | 0.007 | 0.007 | 0.008 | 0.022 | 0.01** | 0.006 | 0.008 |
| Dep. Ratio | -0.528 | 0.688 | 1.590 | 0.890* | 0.173 | 0.847 | 0.756 | 0.777 |
| Extension | -0.144 | 0.368 | -1.16 | 0.40*** | 0.118 | 0.350 | -0.45 | 0.369 |
| Access credit | -0.186 | 0.316 | 1.029 | 0.35*** | 0.420 | 0.311 | 0.265 | 0.313 |
| Ln cash crop | 0.028 | 0.027 | 0.103 | 0.044** | 0.040 | 0.035 | 0.031 | 0.010 |
| Ln off farm | 0.014 | 0.027 | -0.098 | 0.029*** | 0.000 | 0.028 | 0.022 | 0.027 |
| Education | 0.363 | 0.269 | -0.242 | 0.257 | 0.632 | 0.278** | -0.465 | 0.245* |
| hpriceagriinp | -0.411 | 0.373 | 0.461 | 0.406 | -0.340 | 0.304 | 0.727 | 0.336** |
| Infrastructure | -0.171 | 0.263 | 0.920 | 0.261*** | 0.286 | 0.245 | -0.590 | 0.249** |
| lpriceagri | 0.199 | 0.348 | -0.967 | 0.400** | -0.165 | 0.352 | -0.288 | 0.340 |
| Land own | 0.411 | 0.328 | 0.585 | 0.347* | 0.586 | 0.347* | 0.413 | 0.379 |
| Constant | 0.260 | 0.803 | -2.303 | 1.170 | -3.323 | 1.07*** | -2.022 | 0.86** |

Note: *, ** and *** significant at 10 %, 5 % and 1% level respectively.

**4.14.2. Sources of income diversification strategies estimation using SUR**

Table 16 presents coefficient estimates of Seemingly Unrelated Regression (SUR) model for incomes derived from diverse farm enterprises. The null hypothesis was tested using the Breusch-Pagan test for independence of error terms. The test statistic $\chi^2(6) = 16.707, p = 0.010))$ is significant at 1% level of probability and indicates significant correlation of errors terms of the four equations. Hence, the null hypothesis of independence of errors terms is rejected. Therefore, SUR approach is appropriate as oppose to single linear equation estimation or multivariate regression.

Family size was negatively and significantly related with cereals income at 10% levels of probability. In other words, an increase in family size by one member leads to a 0.04 decrease in the income generated from the sale of cereals. This may be construed to mean that the aim of cereals production is for food security purposes. Large size households have many mouths to feed and, therefore, cereals production largely maybe solely for food self-sufficiency rather than for the market. This finding is inconsistent with Olayemi (2012); Kassie *et al*.(2014) and

Dillon and Barrett (2017) who reported that a positive relationship between family size and food consumption.

The level of education of the family head was negatively and significantly associated with livestock income at 10% level of significance. Relative to farmers with no formal education, farmers with primary and higher levels of education generated less income from the sale of livestock. Having primary or higher level of education reduced livestock income earnings by 1.6 units. Higher level of education could possibly enable farmers to generate income from alternative off-farm sources, thereby offsetting the need to sell livestock. It is also worth noting that livestock is a symbol of social status and agricultural development in Southern Mali. Hence, farmers are less likely to sell livestock as it is perceived and considered as store of wealth. Furthermore, smallholder farmers keep livestock as important sources of animal power and manure and, therefore, livestock are not easily sold. This finding is in line with Xu *et al*. (2015) and Kassie *et al*. (2017) who established a negative relationship between level of education of farmers and farm income.

The coefficient of off-farm income was positively and significantly associated with income from the four farm enterprises at 1% level of probability. A 1% increase in the amount of off-farm income results in an increase in the level of income generated from cereals, livestock, vegetable and horticulture by 1.15%, 0.7%, 0.78%, and 0.91% respectively. The results indicate that income from off-farm activities contributes to agricultural production systems in the study area. Off-farm income could be invested in agriculture, allowing farmers to acquire new or improved agricultural technologies which, in turn, lead to increased agricultural productivity and farm income. This finding is consistent with Asfaw *et al*. (2017) who reported that off-farm income is important to rural economic development.

Access to agricultural credit was significant and positively associated with vegetable income at 1% level of significance. Farmers with access to credit generated 3.77 more income from vegetable production compared to farmers who had no access to credit. In other words, access to credit allows farmers to engage in other farm enterprises rather than exclusively relying on cash crop income as the only source of farm income. Access to credit permits agricultural enterprise start-ups and encourages farmers to produce for the market in order to offset the cost of credit. The significant influence of access to credit on vegetable production and sale may also be explained by the tendency of farmer to invest financial resources in high value farm enterprises.

The result is in line with the finding of Khatiwada *et al*.(2017) who reported a positive relationship between credit and agribusiness development in rural areas.

Access to agricultural extension services had a negative and significant relationship with vegetable income at 5% levels of significance. Relative to farmers had no access to extension service, farmers with access to agricultural extension services had 3.19 less income from the sale of vegetable. This result is unexpected since agricultural extension services offer information about agricultural development. This could be attributed to the perishability and seasonality of vegetable production. Vegetable production is rainfall dependent and, therefore, a majority of farmers produce during rainy season. Hence, market dynamics during periods of high vegetable production and extension information that discourage marketing of farm produce when market prices are low could have possibly affected income generated from vegetables.

The state or rural infrastructure (road) had a positive and significant relationship with income generated from vegetable production at 1% level of significance. Farmer who perceived the state of rural roads as good generated 2.77 more income from the sale of vegetables than their counterparts who perceived roads to be in poor state. This indicates that good infrastructure facilitates access to the output market. In addition, good state of rural roads eases the delivery farm product to major centres such as urban markets which increases farm income. In other words, good roads reduce transaction cost and influences farmer decision to participate in vegetable production. The result is similar to the findings of Jari and Fraser (2009) and Tarekegn *et al*.(2017) who found that good roads facilitate farmer participation in output markets. On the other hand, infrastructure had negative and significant relationship with income generated from cereals and horticulture at 10% and 5% levels of probability, respectively. Farmers who perceived roads to be in good state made 1.41 and 1.21 less income from cereals and horticulture, respectively, compared to farmers who perceived roads to be in poor state. This could possibly be explained by differences in farm gate and main market prices. Main market prices were possibly low compared to farm gate prices since good state of roads could have resulted in increased supply of cereals and horticultural products to the market. Some studies have reported that infrastructure is vital for determining market participation (Onoja *et al*.,2012; Abu *et al*., 2016).

Table 16: Seemingly Unrelated Regression (SUR) estimates for multiple sources of income

| | lnfcropincome | | lncatincome | | lnvegtincome | | lnhortinc | |
|---|---|---|---|---|---|---|---|---|
| | Coef. | S E | Coef. | S E | Coef. | S E | Coef. | S E |
| Age FH | 0.002 | 0.030 | 0.033 | 0.032 | -0.002 | 0.033 | -0.016 | 0.020 |
| Education | 1.253 | 0.842 | 1.130 | 0.907 | -1.598* | 0.919 | -0.822 | 0.565 |
| Landown | 0.954 | 1.135 | 0.711 | 1.222 | 0.551 | 1.238 | -0.190 | 0.761 |
| LncashC | -0.084 | 0.108 | -0.036 | 0.116 | 0.148 | 0.118 | -0.026 | 0.072 |
| Lnofffarm | 1.147*** | 0.257 | 0.703*** | 0.276 | 0.780*** | 0.280 | 0.909*** | 0.172 |
| Credit | -1.245 | 1.051 | 0.033 | 1.131 | 3.767*** | 1.146 | 0.031 | 0.705 |
| Extension | -0.694 | 1.207 | 0.614 | 1.299 | -3.187** | 1.316 | -0.155 | 0.809 |
| Infrastructure | -1.462* | 0.838 | 0.035 | 0.903 | 2.774*** | 0.914 | -1.209** | 0.562 |
| Lpagriprdt | 0.163 | 1.113 | -0.365 | 1.198 | -1.543 | 1.214 | -1.100 | 0.746 |
| Hcagrinput | -0.976 | 1.067 | 0.696 | 1.149 | 1.305 | 1.164 | 0.702 | 0.716 |
| Familysize | -0.040* | 0.024 | 0.036 | 0.026 | 0.002 | 0.027 | 0.022 | 0.016 |
| DepRat | -4.172 | 2.548 | 0.836 | 2.743 | 4.476 | 2.779 | 0.144 | 1.709 |
| Constant | -1.763 | 3.363 | -5.441 | 3.621 | -11.683 | 3.668 | -0.292 | 2.256 |
| $R^2$ | 0.20 | | 0.16 | | 0.32 | | 0.31 | |
| F | 32.87*** | | 26.08*** | | 63.26*** | | 59.85*** | |
| Number observations | | | 134 | | | | | |
| Breusch-Pagan test of independence | | | | Chi2(6) = | 16.707 | p= 0.010 | | |

Note: *, ** and *** significant at 10 %, 5 % and 1% level respectively

**4.14.3. Main sources of income share in Southern Mali**

Figure 14 presents the principal source of income in the cotton growing zones in Southern Mali. On average, about 34% of smallholder farmers' income is derived cash crop (cotton) while a combination cereal, horticultural and livestock production accounted for an average of about 41%. On average, about 75% of smallholder farmer's incomes are from agricultural sources such as cotton, cereals (maize, millet and sorghum), horticulture and livestock (cattle). On average, non-farm income contributed to about 21% of total income of smallholder farmers. This finding is consistent with Archibald *et al.*(2014) who reported that off-farm income contributes to about 19.07% of total farm income in Ghana. In Southern Mali, the main activities are traditional gold mining, handcraft and informal trade among others. However, Senadza (2012) found that off-farm income accounted for about 43% of the total smallholder farmers' income in rural area in Ghana.

The natural resources income generating activities are mainly composed of Shea nut (extraction of oil), firewood and charcoal sale. These income sources contribute to about 4% of the total smallholder farmers' income in Southern Mali. Rural smallholder farmers' incomes are broad, extremely heterogeneous with connection between farm and nonfarm activities (Barrett *et al*., 2000; Haggblade *et al*.,1989).

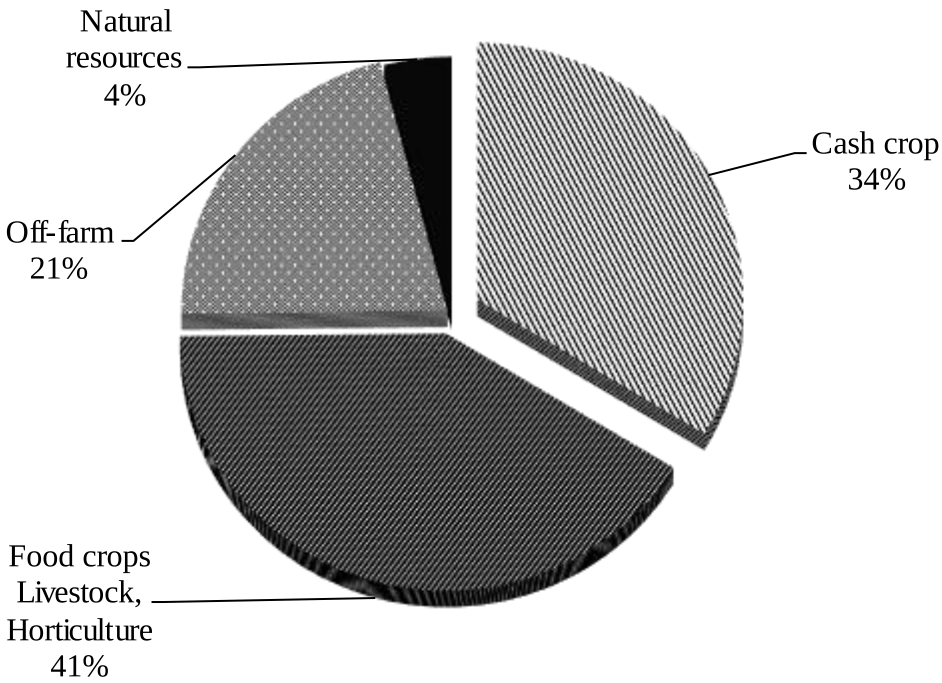


Figure 14: Income share across main enterprises

## 4.15. Determinants of crops diversification strategies in Southern Mali

### 4.15.1. Econometrics analysis Multinomial logistic regression (MNL)

Multinomial logistic regression was used to determine factors influencing choice of alternative diversification strategies. Cereals production was selected as the base category with full results from the MNL presented in Table 17. The model was highly significant as indicated by likelihood ratio test (LR $\chi^2(30) = 119.72$, $p = 0.000$), suggesting strong explanatory power of the model. The variables were tested for multicollinearity using the variance inflation factor (VIF). The variance inflation factors for all variables were less than 10, indicating absence of multicollinearity. Out of the ten explanatory variables included in the model, four variables influenced farmers' decision to diversify into a combination of cotton and maize. Five variables influenced diversification into a combination of cotton and two cereals (maize and millet) and cotton and three cereals (maize millet sorghum).

Age of family head was positively and significantly associated with the probability of diversification at 5% and 10% significance levels. Elderly farmers were more likely to either engage in cotton and maize, cotton and two cereals or cotton and three cereals production relative to only engaging in cereals production. This implies that the likelihood of diversification into several crop enterprise increases with age of the farmer. This probably implies that older farmers put much emphasis on family food security and increased income. Besides producing cereals for consumption purposes, older farmers engage in cash crop production in order to earn additional income. On the other hand, these three groups of smallholder farmers are large families and get inputs through their participation in cotton production. This allows farmers to apply a significant proportion of the inputs on maize, the main cereal crop. This also implies that the older heads of families are interested in maintaining cash crop production and seek to feed the family while younger heads of families are mainly interested in ensuring food self-sufficiency. This finding is consistent with results of studies by Deressa *et al*. (2009); Teklewold *et al*.(2013); Meraner *et al*.(2015) and Gautam and Andersen (2016) who found that age positively affected diversification decisions. On the other hand, Hassan and Nhemachena (2008) and Aneani *et al.* (2011) indicated that the age of smallholder farmers increased the probability of diversification in order to improve livelihoods.

Family size variable had a positive and significant effect on the probability of diversification at 5% significance level. This implies that large families are more likely to grow a mixture of cash and cereals. Large families are able to engage in multiple cropping systems as compared to smaller families. In cotton growing zone of Mali, access to factors of production such as land and labour contribute to smallholder farmers' decisions to diversify. Therefore, family size has a significant association with these diversification strategies in agricultural production systems. This finding is in line with results reported by Babulo *et al*. (2008); Kassie *et al*. (2012) and Piya and Lall (2013) who found that families with high labour availability are more likely to diversify into several agricultural enterprises.

Education is an important factor influencing diversification of livelihood strategies. The education level of the family head positively and significantly influenced diversification of crop enterprises. Well-educated heads of family were more likely to engage in cotton and two cereals (maize and millet) and cotton and three-cereals production compared to cereals growers. Similarly Onya *et al*. (2016); Zereyesus *et al*. (2016) and Asfaw *et al.* (2018) found that highly educated smallholder farmers were more likely to engage in several enterprises in order to improve their livelihoods. In addition, the finding is consistent with Jansen *et al*.(2006); Rahut & Scharf (2012) and Rahut *et al*. (2014) who found a positive relationship between education level and income diversification strategies.

Oxen ownership had a positive and significant influence on the probability of diversification at 5% and 10% significance levels. An increase in the number of oxen owned by smallholder farmers increased the likelihood of diversifying into cotton and maize, cotton and two cereals and cotton and three cereals as opposed to engaging only in cereals production. Oxen constitute the main source of animal power for agricultural work. All agricultural work such as ploughing, seeding and transportation of farm input and output utilizes animal power. Oxen ownership permits cultivation of larger areas of arable land and provides manure, an important farm input. This explains the low use of tractor and others machineries in Southern Mali. This finding is consistent with Cunguara and Darnhofer (2011); Ghimire *et al*. (2014) and Khonje *et al*. (2015) who suggested oxen provide animal power for ploughing in rural areas in SSA due to lack of tractors and small size of cultivated land area.

Farm income had a positive and significant relationship with diversification into cotton and maize and cotton and three cereals at 10% and 5% significance levels respectively. Higher incomes allow farmers to have access to critical productive resources such farm assets, inputs and land which increase the likelihood of crop diversification. The extra income earned by farmers from one crop is also important in providing financial resources that are used for diversification into other crops. This finding underlines results by Basantaray and Nancharaiah (2017) who indicated that crop diversity is strongly associated with significantly higher farm income.

Threat to production by pests was negatively and significantly associated with diversification into cotton and two cereals at 10% level. The possible explanation for this negative direction in the relationship between crop pest and crop diversification is that pests cause crop damage which discourage diversification into cotton and two cereals. The cereals may be prone to the same pests, dis-incentivizing farmers from diversifying. This finding is inconsistent with (Murrell, 2017) who reported that diversification of crops has a potential of suppressing and breaking down pest lifecycles.

Table 17: Multinomial Logistics Regression model on crop diversification strategies

| Explanatory variables | Cotton+ Maize | | Cotton+2Cereals | | Cotton+3Cereals | |
|---|---|---|---|---|---|---|
| | Coef. | P>z | Coef. | P>z | Coef. | P>z |
| Age | 0.308** | 0.042 | 0.297** | 0.049 | 0.286* | 0.058 |
| Family size | 1.171** | 0.033 | 1.135** | 0.038 | 1.167** | 0.033 |
| Education | 4.574 | 0.218 | 7.612** | 0.038 | 8.591** | 0.019 |
| Oxen | 2.898* | 0.072 | 3.331** | 0.039 | 3.258** | 0.044 |
| Ln nonfarm | 0.322 | 0.191 | 0.398 | 0.111 | 0.368 | 0.141 |
| Lagriinput | -3.237 | 0.239 | -2.699 | 0.330 | -2.360 | 0.396 |
| hcostagriinput | -4.711 | 0.404 | -6.650 | 0.238 | -6.879 | 0.222 |
| Ln income per capita | 0.500* | 0.067 | 0.394 | 0.107 | 0.503** | 0.051 |
| Crops pest | -4.852 | 0.121 | -5.423* | 0.085 | -4.736 | 0.133 |
| Extension | -6.514 | 0.995 | -6.148 | 0.995 | -5.294 | 0.996 |
| Constant | -21.167 | 0.983 | -20.098 | 0.984 | -22.159 | 0.982 |
| Base category/reference | | Cereals | | | | |
| Number of observation | | 134 | | | | |
| LR Chi2(30) | | 119.72 | | | | |
| Prob > Chi2 | | 0.000 | | | | |
| Pseudo $R^2$ | | 0.357 | | | | |
| Log likelihood | | -107.987 | | | | |

Note: *, ** significant at 10% and 5% levels respectively.

**4.15.2. Hypotheses**

Table 18 provides test results of the two hypotheses. The test statistics for hypothesis 1 (Chi2 = 32.11; p value = 0.006) suggest that socioeconomic factors considered such as age of family, family size, oxen education, non-farm and farm income jointly influence crop diversification. Therefore, we reject the null hypothesis and conclude that socioeconomic factors significantly influence crop diversification. Further, the test statistic for Hypothesis 2 (Chi2 =2.04; p = 0.566) suggest that the coefficient of extension services is not statistically different from zero. Therefore, we fail to reject the null hypothesis and conclude that extension services have no significant influence on crop diversification.

Table 18: Hypotheses test statistics of MNL

| Hypotheses | Chi2 | p- Value | Decision |
|---|---|---|---|
| $H_1$: $\mu_1 = 0$; $H_a : \mu_1 \neq 0$ | 32.11 | 0.006*** | $H_1$ rejected |
| $H_2$: $\mu_2 = 0$; $H_a : \mu_2 \neq 0$ | 2.04 | 0.564 | Fail to reject $H_2$ |

Note: $H_1$ = null hypothesis and $H_a$ = alternative hypothesis for socioeconomic factors and significant at 1% level and $H_2$ = null hypothesis and $H_a$ = alternative hypothesis for access to agricultural extension services

### 4.16. Stochastic frontier of production function of main crops

#### 4.16.1. Production frontier for cotton

Table 19 presents the maximum likelihood estimates (MLE) of the parameters of Cobb Douglas stochastic frontier production function. It also shows the inefficiency effects and idiosyncratic effects in the model. The results revealed that quantity of NPK per hectare had a positive significance at 1 % level of probability. That is, an increase in the use of NPK input per hectare would lead to increase cotton output. The coefficient of NPK applied was 0.36 which showed that cotton output is elastic to changes in the application of NPK. A 1 % increases in NPK use will lead to a 36.2 % increase of cotton output. This implies that NPK is one of the most important factors of cotton production and had a strong influence on yield per hectare. The results are consistent with previous studies Girei *et al*.( 2013); Theriault and Serra ( 2014); Mango *et al*. (2015) and Kea *et al*. (2016) who found out that there was a positive effect of NPK use on production in cotton and cereals in West Africa, Cambodia and Zimbabwe. This result is also in line with the findings of study carried out in Ghana, Sudan and Uzbekistan (Adzawla *et al*., 2013; Karimov *et al*., 2014; Mahgoub *et al*., 2017).

#### 4.16.2. Idiosyncratic effects

Table 19 shows the specific characteristic of farmers to maintain their cotton plot. The explanatory variables such as frequencies of insecticide application and weeding are the greatest challenges in contributing to the best cotton output. The coefficient of insecticide applied per hectare had a positive and significant relationship with cotton output at 5% levels. In cotton cropping, the frequency of applying insecticide is at least 6 times starting from the point of a distinguished first flower until harvesting. This implies that at least cotton farmer applied insecticides at the normal frequency recommended by research and agricultural extension services. Additionally, the positive coefficient for frequency of insecticide applied influenced cotton output per hectare. Hence applying the optimum frequency of insecticide at the appropriate time is expected to increase cotton output per hectare due to the reduction of insect pests. The variable frequency of weeding was negatively and significantly associated with output of cotton at 1% level. This was unexpected, since a higher frequency of weeding (twice) would be expected to have a positive effect on cotton output. This would be attributed to the availability of labour at the time where the agricultural work was at its peak. However, decreasing effect of higher frequency of weeding could also be explained by the number of crop enterprises that farmers are engaged in. This result confirms the finding of (Mahgoub *et al*., 2017)

**4.16.3. Factors explaining technical inefficiency**

The parameter estimates of the inefficiency effects of stochastic production frontier model are shown in the last section of Table 19, on socio - economics and institutional factors. The parameters include age of family head, education, family size, cotton plot size (ha), land and oxen ownership, agricultural tools as well as institutional factors such as access to agricultural credit and access to agricultural extension services. The results show that, age of family head and family size were significant on cotton cropping system. The coefficient of age was negative and significantly associated with cotton output at 5% levels. This implies that an increase in age of family head led to an increase in technical efficiency. In other words, young farmers were more technically inefficient than the older ones. This is explained by the work force that is, the adoption of new agricultural practices is more engaging for young farmers as opposed to older farmers who meet challenges in conducting good agricultural practices. This result is in line with the findings of (Bozoglu and Ceyhan, 2007; Okoye et a*l*., 2016). The coefficient of family size was positive and significant at 5% levels of probability. This implies that a larger family sizes were more technical inefficient than smaller family sizes. This could be explained by larger family sizes having pressure on available resources hence tend to be poor as compared to small sized families and struggling to survive. This finding is inconsistent with Abdul-rahaman (2016) who reported that age increased technical efficiency of cotton farmers in Northern region of Ghana.

Table 19: Maximum likelihood estimates of stochastic frontier production

| Ln Yield/ha cotton | Coef. | Std. Err. | P>z |
|---|---|---|---|
| **Production function** | | | |
| Ln plot size(ha) | -0.082 | 0.062 | 0.184 |
| Ln NPK/ha | 0.362*** | 0.092 | 0.000 |
| Ln Urea/ha | -0.118 | 0.143 | 0.408 |
| Ln Labour | 0.023 | 0.045 | 0.610 |
| Ln Qtty insect | 0.012 | 0038 | 0.758 |
| Constant | 5.899 | 0.658 | 0.000 |
| **Idiosyncratic effects** | | | |
| Frequency insecticide applied | 0.403** | 0.193 | 0.037 |
| Frequency weeding | -2.559*** | 0.727 | 0.000 |
| Constant | -0.853 | 0.960 | 0.374 |
| **Inefficiency effects** | | | |
| Age of family head | -0.035** | 0.015 | 0.018 |
| Family size | 0.030** | 0.015 | 0.040 |
| Land ownership | 0.273 | 0.616 | 0.658 |
| Education | 0.077 | 0.378 | 0.839 |
| Extension services | 0.249 | 0.728 | 0.732 |
| Access to credit | -0.288 | 0.517 | 0.577 |
| Oxen ownership | -0.151 | 0.138 | 0.274 |
| Agricultural tools | -0.125 | 0.146 | 0.393 |
| Number of plot | 126 | | |
| Wald chi2 (5) | 16.15 | | |
| Prob>chi2 | 0.006 | | |
| Log likelihood | -35.389 | | |

Note: **, ***, significant at 5% and 1% level respectively

#### 4.16.4. Distribution of technical efficiency (TE) scores

The mean technical efficiency (TE) was 84 % and ranged between 29% and 100% as shown in Table 20. The results are in the line with the findings reported by (Neba *et al.*, 2010 and Karimov, 2014). This implies that cotton producers of Southern Mali are more technically efficient which could be explained by the level of TE scores.

The mean level of technical efficiency was 84%, which indicates that on average, cotton output falls 16 % in the short run of the maximum possible level. Therefore, in the short run it is possible to increase cotton production by an average of 16% by adopting the available technologies. The results mean that cotton producers operated at above half of the production frontier. On the other hand, farmers with the best agricultural practices lay in fully production frontier while, the worst producers had a TE of 29%. The distribution of technical efficiency scores across 126 cotton producers showed that 11.11% of farmers had technical efficiency scores that were less than 60%. Further, 32.54% level farmers had technical efficiency scores between 60 to 89% and the majority of farmers 56.35% of farmers had the most technical efficient score above 90%.

Table 20: Distribution of technical efficiency score (cotton)

| TE score | Frequency | % | Cumulative %age |
|---|---|---|---|
| 0.29-0.39 | 3 | 2.38 | 2.38 |
| 0.40-0.49 | 2 | 1.59 | 3.97 |
| 0.50-0.59 | 9 | 7.14 | 11.11 |
| 0.60-0.69 | 10 | 7.94 | 19.05 |
| 0.70-0.79 | 14 | 11.11 | 30.16 |
| 0.80-0.89 | 17 | 13.49 | 43.65 |
| >0.90 | 71 | 56.35 | 100.00 |
| Number Observation | 126 | | |
| Mean | 0.84 | | |
| SD | 0.16 | | |
| Min | 0.29 | | |
| Max | 1 | | |

### 4.16.5. Production frontier for Maize

Table 21 presents the Maximum likelihood (MLE) estimates using Cobb-Douglas stochastic frontier production function model. The coefficients of the inputs urea and plot size were negative and significant while the coefficients of labour and NPK per hectare were positive and significant. The positive effects of these inputs on output were as expected, since availability of labour and quantity of NPK applied per hectare should increase the production. Whereas, the negative sign of urea applied per hectare and plot size was surprising, due to their expected positive effect on production. The elasticity coefficients of labour and NPK applied per hectare are statistically significant and positive at 1% level of probability. These results imply that a % increase in labour and NPK applied per hectare would increase maize output by 4.2% and 34.6% respectively. The result are in line with the findings reported by (Chiona *et al.*, 2014; Mango *et al.*, 2015; Okuyama *et al.*, 2017) . The elasticity of urea applied per hectare and plot size were negative and significant at 1% level of probability respectively although the coefficients were inelastic. This implies that a % increase in quantity of urea applied per hectare and plot size of maize would decrease maize output by 2.6% and 2.9% respectively. This is an unexpected figure and could be explained by the inefficient use of these inputs.

**4.16.6. Idiosyncratic effects**

The coefficient of idiosyncratic effect was not significant, indicating no difference among smallholder farmer's practices in maize production in Southern Mali.

**4.16.7. Inefficiency effects of maize production**

The estimated determinants for maize production relating to socio economics characteristics, and institutional factors were mentioned in the third section of Table 21. The parameters included age of family head, family size, education level, access to credit and extension services, low agricultural inputs applied per hectare, oxen ownership, farm income, off income and maize plot size. The results showed that the variables access to agricultural extension services, off farm income and low agricultural inputs applied per hectare had a significant impact on technical efficiency of maize production in Southern Mali.

The coefficient of access to agricultural extension services was negative and significantly related to the technical inefficiency at 5% level of significance. This implies that more contact with extension agents increased the technical efficiency by providing advices, information on maize production challenges and new agricultural technologies. The results were consistent with the findings reported by (Seyoum *et al.*, 2000; Bempomaa and Acquah, 2014; Mango *et al*., 2015). The coefficient of low agricultural inputs applied per hectare was positive and statistically significant at 5% levels of probability on technical efficiency. This indicates that the low agricultural inputs used decrease farmer technical efficiency. This is due to the diversion of inputs for others crops such as millet sorghum also rice which are not supported by the company. Off –farm income was positive and significant at 1% level of probability. This implies that off-farm income was another determinant of technical efficiency. This is explained by the fact that farmers with various sources of income are less likely to concentrate on agriculture. In other words, farmers who concentrate more on off-farm income generation activities decrease the technical efficiency due to the inadequacy of time and labour for agricultural businesses. This is consistent with Dlamini *et al*. (2012) who reported that off-farm income affects maize farmers technical efficiency.

Table 21: Maximum likelihood estimates of stochastic frontier production (maize)

| Ln Yield | Coef. | Std. Err. | P>z |
|---|---|---|---|
| **Production function** | | | |
| Ln labour | 0.042*** | 0.017 | 0.000 |
| Ln NPK (kg/ha) | 0.346*** | 0.024 | 0.000 |
| Ln Urea (kg/ha) | -0.026*** | 0.009 | 0.000 |
| Ln Plot size (ha) | -0.029*** | 0.004 | 0.000 |
| Constant | 6.445 | 0.000 | 0.000 |
| **Inefficiency effects** | | | |
| Age of family head | 0.003 | 0.009 | 0.728 |
| Family size | -0.003 | 0.010 | 0.798 |
| Access to credit | -0.376 | 0.333 | 0.258 |
| Oxen ownership | -0.075 | 0.075 | 0.317 |
| Education | 0.456 | 0.281 | 0.105 |
| Extension services | -0.805** | 0.391 | 0.040 |
| Low agri inputs applied | 0.652** | 0.279 | 0.019 |
| Ln on farm income | -0.100 | 0.085 | 0.238 |
| Ln off farm income | 0.073*** | 0.028 | 0.009 |
| Hectare plot(ha) | -0.010 | 0.066 | 0.879 |
| Constant | -0.240 | 1.104 | 0.828 |
| Number of observation (plots) | | 133 | |
| Wald chi2(4) | | 2.800 | |
| Prob>chi2 | | 0.000 | |
| Log likelihood | | -47.253 | |

Note: **; *** significant levels at 5% and 1% respectively

**4.16.8. Technical efficiency and distribution of technical efficiency scores (maize)**

Table 22 presents the frequency of distributions for technical efficiency. It shows that the technical efficiency indices ranged from 6.5 to 100% with mean technical efficiency estimated about 58%. This result is inconsistent with the previous findings reported by Ahmed *et al*. (2014); Esham (2014) and Sapkota *et al*. (2017) where the TE were 88% and 72 to 71% in Ethiopia, Sri-Lanka and Nepal respectively. The result implies that on average, farmers could produce about 58% of their potential maximum maize output from a given set of inputs and technologies. The distribution of technical efficiency scores shows that about 40.60% of farmers were found to have a technical efficiency score at 40% levels. At 45.11%, level farmers had a technical efficiency score ranked between 50 to 70% and 14.29% of farmers having technical efficiency above 70%.

Table 22: Distribution of technical efficiency scores (maize)

| TE score | Frequency | % | Cumulative %age |
|---|---|---|---|
| <0.20 | 5 | 3.76 | 3.76 |
| 0.20-0.30 | 23 | 17.29 | 21.05 |
| 0.30-0.40 | 26 | 19.55 | 40.60 |
| 0.40-0.50 | 27 | 20.30 | 60.90 |
| 0.50-0.60 | 17 | 12.78 | 73.68 |
| 0.60-0.70 | 16 | 12.03 | 85.71 |
| 0.70-0.80 | 10 | 7.52 | 93.23 |
| 0.80-0.90 | 8 | 6.02 | 99.25 |
| 0.90-1.00 | 1 | 0.75 | 100.00 |
| Number observation | 133 | | |
| Mean | 0.58 | | |
| SD | 0.2 | | |
| Min | 0.065 | | |
| Max | 1 | | |

### 4.16.9. Production frontier for millet

The parameters of maximum likelihood estimates (MLE) of stochastic frontier production function, the idiosyncratic effects and inefficiency effects are reported in the Table 23. The first section of table presents the production function. The coefficients of inputs used in the production are explained in terms of output elasticities. The coefficient of labour was positive and significant at 1% level. This indicates that a 1% increase in labour would lead to a 7.4 % increase in millet output. This is explained by the availability of labour considering that millet production is labour intensive. The coefficient of urea applied per hectare had a positive and significant at 1% level. A 1% increases in the quantity of urea applied per hectare would lead to a 1.8% increase in millet output. In cotton production zones of Mali, the quantity of urea applied is still low due lack of subsidies of millet and sorghum inputs. The coefficients of land size under millet and NPK applied per hectare were negative and significant at 1% level of probability. This implies that a % increase in NPK applied per hectare would lead to a 8.2% decrease in millet output. This was an unexpected sign since application of NPK on a crop is expected to increase its output. This is attributed to the low quantity of NPK applied per hectare or not applied under millet for certain farmers. The coefficient of land area allocated was also negative, which meant that a 1% increase in land size of millet would result to a 3.3% decrease in millet output. This is due to the maintaining of plot in terms of availability of inputs.

### 4.16.10. Idiosyncratic effects on production

This section of table shows that some difference of practices among smallholder farmers in millet production. The significant variable is the frequency of weeding. The coefficient of frequency of weeding was negative and significant at 1% level of significance. This implies that the number of weeding for crop operation is decreasing in Southern Mali. This fact is explained by the availability of work force at spike of crop operations.

### 4.16.11. Inefficiency effects of millet production

The variables estimate of the inefficiency effect of stochastic production frontier function are shown in the third part of Table 23. The results show that access to agricultural credit, access to agricultural extension services, non-farm income and education level had a significant impact on technical efficiency among smallholder farmers in Southern Mali. The coefficient of access to agricultural credit was negative at 10% and significantly influenced the relationship with technical inefficiency. This implies that access to agricultural credit improves farmer's technical efficiency of millet production in cotton growing zone of Mali.

This result is similar to the finding of (Nwaru *et al.*, 2011). Access to agricultural credit encourages farmers to diversify their enterprises, allows them to acquire needed inputs. Agricultural credit facilities also contribute to better adoption of agricultural technologies and innovative farming. The access to extension services had a positive and significant relationship with technical inefficiency at 1% level of probability. This implies that the number of contacts with extension services decrease the technical efficiency. This is unexpected since extension services provide advice, information about good agricultural practices and innovation in relation with production. The coefficient of non-farm income is positive and statistically significant at 5% level of significance. This indicates that non-farm income decreases the technical efficiency. More non-farm income activities influence farmers to engage in agricultural production sector. On the other hand, with various sources of nonfarm activities, farmers are more likely to divert from crop production and emphasize on non-farm income generation activities. The education level of family headed was negative and statistically significant at 5% levels of probability. The results indicate that high level of education for millet farmers contributes to technical efficiency. This finding is in line with Binam *et al*.(2008) and Girei *et al.*, 2013) who reported that farmer with formal schooling are more likely to be efficient in cereals production in Cameroon and Nigeria.

Table 23: Maximum likelihood stochastic frontier production function (millet)

| lnYield_Ha | Coef. | Std. Err. | P>z |
|---|---|---|---|
| **Production function** | | | |
| Ln labour | 0.074*** | 0.006 | 0.000 |
| Ln NPK_ha | -0.082*** | 0.003 | 0.000 |
| Ln Urea_ha | 0.018*** | 0.002 | 0.000 |
| Ln plot size (ha) | -0.033*** | 0.005 | 0.000 |
| Constant | 6.558*** | 0.022 | 0.000 |
| **Idiosyncratic effects** | | | |
| Frequency weeding | -11.264*** | 2.800 | 0.000 |
| Constant | 10.400 | 2.830 | 0.000 |
| **Inefficiency effects** | | | |
| Age of family head | 0.010 | 0.030 | 0.740 |
| Land ownership | 2.141 | 1.948 | 0.272 |
| Oxen ownership | 0.133 | 0.205 | 0.514 |
| Agri. tools | -0.189 | 0.192 | 0.324 |
| Access credit | -1.752* | 0.942 | 0.063 |
| Extension services | 2.354*** | 0.776 | 0.002 |
| Ln off farm | 0.196** | 0.089 | 0.027 |
| Education | -4.501*** | 0.835 | 0.000 |
| Plot size (ha) | -0.421 | 0.320 | 0.189 |
| Constant | -3.710 | 2.431 | 0.127 |
| No of plot | 63 | | |
| Wald chi2(4) | 1579.81 | | |
| Prob > chi2 | 0.000 | | |
| Log likelihood | -32.305 | | |

Note: ***, **, significant at 1 % and 5 % level respectively

**4.16.12. Distribution of technical efficiency scores (millet)**

The results of stochastic frontier model showed that the mean technical efficiency was 0.58 for millet producers as shown in Table 24. This implies that farmers practicing millet was 58% technically efficient. This shows that farmers produced millet below the frontier level and there is a scope to increase technical efficiency by 42 % in the short-run under the existing technology. The distribution of technical efficiency score ranged between 15 to 99%.

The distribution of technical efficiency (TE) scores indicates that 42.86 % of farmers had efficiency scores of less than 40%, and 28.57% of farmers had technical efficiency scores of between 50 and 70% while 28.58% of farmers had efficiency scores above 80%.

Table 24: Distribution of technical efficiency scores (millet)

| TE scores | Frequency | % | Cumulative %age |
|---|---|---|---|
| <0.20 | 20 | 31.75 | 31.75 |
| 0.20-0.30 | 4 | 6.35 | 38.10 |
| 0.30-0.40 | 3 | 4.76 | 42.86 |
| 0.40-0.50 | 4 | 6.35 | 49.21 |
| 0.50-0.60 | 5 | 7.94 | 57.14 |
| 0.60-0.70 | 3 | 4.76 | 61.90 |
| 0.70-0.80 | 6 | 9.52 | 71.43 |
| 0.80-0.90 | 8 | 12.70 | 84.13 |
| 0.90-1.00 | 9 | 14.29 | 98.41 |
| 1.00 | 1 | 1.59 | 100.00 |
| Number of plot | 63 | | |
| Mean | 0.58 | | |
| SD | 0.24 | | |
| Min | 0.15 | | |
| Max | 0.99 | | |

**4.16.13. Production function for sorghum**

The maximum likelihood estimates using Cobb Douglas stochastic production frontier parameters are presented in the Table 25. The estimated coefficient of elasticity of labour was significant. The variable labour was positively and significantly associated with yield per hectare at 1% level of significance. This implies that a 1% increase in labour utilized in sorghum operation would lead to a 23.7% increase in sorghum output. The coefficient of inorganic quantity applied per hectare under sorghum was negative and significant at 1% level of significance. This implies that a 1% increase in inorganic fertilizer would lead to a 5.6% decrease in sorghum output. This is in contrast to a priori expectation, since fertilizer use is expected to increase crop output. The possible explanation is attributed to low quantity of inorganic fertilizer applied per hectare in cotton production zone of Mali. This finding is in contradiction with Ahmed *et al*. (2005) who reported a positive relationship between fertilizer used under sorghum and yield in Sudan.

### 4.16.14. Idiosyncratic effects on sorghum production

The middle part of the Table 25 shows crop management operations for sorghum production and differences of practices undertaken by farmers. The variables quantity of NPK applied per hectare, quantity of Urea applied per hectare and the frequency of weeding had significant influence on farmer's practices. The coefficient of NPK applied per hectare was positive and statistically significant at 1% level of probability and increases technical efficiency. This implies that farmers applied low quantity of NPK on sorghum. This is explained by the lack of subsidy of agricultural inputs for sorghum and millet. Additionally, cash constraints contribute to the low use of NPK under sorghum. Only wealthy families buy the NPK for cereals (sorghum and millet) at the market, hence, the low application of NPK in cotton growing zone of Mali. This result is similar to the finding of Zalkuwi *et al*. (2015) who reported that the use of chemical fertilizer increases the output of sorghum in India. The coefficient of Urea was negative and statistically significant at 1% level of probability. This implies that less quantity of Urea applied under sorghum improves the level of technical efficiency.

In addition, farmers apply NPK or Urea on one crop (millet or sorghum) in order to increase the production. The frequency of weeding was positive and statistically significant at 1% level of probability. The results showed that weeding of sorghum plot improves farmer's technical inefficiency. Weeding sorghum plot twice is rare though is recommended by research and extension services. Additionally, it improves the yield per hectare and protects the crop from any weed and probably farmers incurring extra credit on herbicide. Mohamed *et al*. (2008) found out a negative association between the frequency of weeding and sorghum productivity which influence sorghum output in rain-fed agriculture.

### 4.16.15. Inefficiency effects of technical efficiency

The estimated determinants of technical inefficiency of sorghum production activities are presented in the last section of Table 25.The main determinants were access to agricultural extension services, oxen ownership and off farm income. The coefficient of access to agricultural extension services was positive and significant at 5% levels. Since extension services provide farmer with advices, information flow on good agricultural practices and new technologies and hence, expected to be technically efficient. This is similar to the findings of Chepng'etich *et al*. (2015) in Lower Eastern Kenya. The coefficient for oxen ownership was negative and statistically significant at 1% level of significance.

This implies oxen ownership contribute to the improvement of sorghum, where animal's owners are technical efficient. This is also explained by the level of livestock ownership in the study, where at least each farming family has oxen. Oxen play an important role of the agricultural development in the cotton growing zone of Mali. This could be because not only are oxen and livestock a source of manure to the farm but they are also a critical source of power. The coefficient of off-farm income was positive and statistically significant at 5% levels of significance. This implies that off –farm income decreases technical inefficiency of farmers. Participation in off-farm activities beside crop and livestock production discourages farmers to invest in agricultural sector. On the hand, off-farm activities could be a factor that contributes negatively on crop production leading to the technical inefficiency. This is inconsistent with Tijani (2006) who argued that off-farm income had a positive effect on technical efficiency of farmers in rice production zone of Osun State, Nigeria.

Table 25: Maximum likelihood stochastic frontier production function

| Ln Yield_ha | Coef. | Std. Err. | P>z |
|---|---|---|---|
| **Production function** | | | |
| Ln plot size(ha) | 0.072 | 0.057 | 0.205 |
| Ln Fert | -0.056*** | 0.014 | 0.000 |
| Ln labour | 0.237*** | 0.051 | 0.000 |
| constant | 5.734*** | 0.216 | 0.000 |
| **Idiosyncratic effects** | | | |
| NPK (kg/ha) | 0.061*** | 0.014 | 0.000 |
| Urea (kg/ha) | -0.081*** | 0.029 | 0.004 |
| Frequency weeding | 1.452*** | 0.517 | 0.005 |
| Constant | -5.311** | 0.770 | 0.000 |
| **Inefficiency effects** | | | |
| Age | -0.021 | 0.031 | 0.499 |
| Family size | -0.042 | 0.073 | 0.569 |
| Plot size (ha) | 0.826 | 0.708 | 0.243 |
| Education | -1.315 | 1.079 | 0.223 |
| Access to credit | 0.498 | 0.995 | 0.616 |
| Extension services | 2.063** | 0.988 | 0.037 |
| Land ownership | -0.600 | 1.199 | 0.619 |
| Agri. Tools | 0.632 | 0.399 | 0.113 |
| Oxen ownership | -0.965* | 0.544 | 0.076 |
| Ln farm income | -0.068 | 0.143 | 0.632 |
| Ln off farm | 0.540** | 0.237 | 0.023 |
| Constant | -6.462 | 3.968 | 0.103 |

Note:*, **, *** significant at 10%, 5% and 1% levels respectively

#### 4.16.16. Distribution of technical efficiency scores (Sorghum)

The distributions of technical efficiency scores across sorghum farmers are presented in Table 26.The mean technical efficiency was 0.80 (80%) which ranged between 21 to 99%. This indicates that farmers had an opportunity to reduce in the short run sorghum production by 20% by undertaking good agricultural practices as technically efficient farmers. This result is inconsistent with the previous findings reported by Chepng'etich *et al*.(2014) and Naim *et al*.( 2017) who find out the TE were 41 % and 78% who find out the TE were 41%

and 78% in Eastern Kenya and Sudan respectively. The results indicate that 14.04% of farmers have technical efficient score below 50%, 22.81% of farmer's have technical efficiency from 50 up to 80%, and 63.16% of farmers having technical efficiency above 80%.

Table 26: Distribution of technical efficiency scores (sorghum)

| TE scores | Frequency | % | Cumulative %age |
|---|---|---|---|
| <0.30 | 4 | 7.02 | 7.02 |
| 0.30-0.40 | 2 | 3.51 | 10.53 |
| 0.40-0.50 | 2 | 3.51 | 14.04 |
| 0.50-0.60 | 0 | 0 | 0 |
| 0.60-0.70 | 8 | 14.04 | 28.07 |
| 0.70-0.80 | 5 | 8.77 | 36.84 |
| 0.80-0.90 | 11 | 19.30 | 56.14 |
| >0.90 | 25 | 43.86 | 100 |
| Number of plot | 57 | | |
| Mean | 0.80 | | |
| SD | 0.23 | | |
| Min | 0.21 | | |
| Max | 0.99 | | |

**4.17. Agricultural technologies practice in southern Mali**

**4.17.1. Cotton system: using logistic regression model**

The estimated coefficients of parameters in the binary logistic model are summarized in Table 27: Determinants of organic matter practices (logit regression). The Chi2-square test statistic was significant at 1% level. The power of prediction of the estimated model was 0.7373 which suggested that approximately 74% of observations were predicted by the logistic regression model. The variables such as education level, labour, transhumance, origin of head of farming family and the frequency of weeding were the significant factors in the adoption and use of organic matter technology among smallholder farmers in Southern Mali. The coefficient of education level was negative and statistically significant at 5% levels. This was unexpected since better educated farmers are more likely to adopt agricultural technologies practices than those who are less educated. This is explained by the low number of farmers who attend formal school. The estimated marginal effect of this variable indicates that the probability of adopting the technology of organic matter application decreases by

47% for farmers who have not attended and farmers who had a primary and other level in formal schooling.

This is not in line with Ghimire *et al.* (2014) and Sodjinou *et al*. (2015) who found out that level of education plays an important role in the adoption of agricultural technology.

The variable labour is an important determinant in adoption of technology in agricultural practices. The coefficient was positive and statistically significant at 1% level of significance. The estimated marginal effect indicates that the probability of organic matter technology adoption increases by 21% for a unit increase in availability of labour. On the other hand, the adoption of organic matter production requires several labour hours to produce large quantity and quality of organic matter. In the study area, farmers mobilize residues from cotton, maize sorghum and millet for organic manure production where animal manure intervene and for compost without animal manure intervention. The result is consistent with Bamine *et al.* (2002) who argued labour is among essential production factor for agricultural technology adoption. This is not in line with the finding of Audu and Aye (2014) who found out that negative relationship to the adoption of agricultural technology in Nigeria.

The coefficient of transhumance was negative and statistically significant at 1% significance level. This implies that an adoption of organic matter production in the study area would lead to a 40% decrease in transhumance. This negative effect is explained by the time that cattle stay within the village which varies between four and five months per year according the villages. In addition, certain farming families have their herd size (cattle) outside the country for one year. These facts affect negatively the organic matter production. On the other hand, the pressure on natural resources (pasture zones) is critical and lead to the long transhumance of herd size. This phenomenon constitutes a challenge for agricultural production system mainly integration of crop and livestock systems.

The effect of origin of family was negative and statistically significant at 5% significance level. The estimated marginal effect indicated that the adoption of organic matter production for new resident in the village decreases at around 21%. This implies that agricultural technology adoption requires certain level of factors endowments such as labour and herd ownership. In other words, the new comers seek food security first and then start to look for agricultural equipment (plough, cart, donkey, oxen).

The frequency of weeding was negative and statistically significant at 5% level of significance. The magnitude of the marginal effect of variable frequency of weeding indicates that the probability of application of organic matter production decreases by 23% for a unit increase in frequency of weeding.

In other words, application of organic matter requires at least two times of weeding in a season to avoid the competition between crop and weed. It is rare for farmers weed correctly twice for the same crop. The frequency of weeding has a positive effect on crops yield and decreases the output where the crop is dominated by the weed.

Table 27: Determinants of organic matter practices (logit regression)

| Organic matter (dependent Yes=1,No=0) | Coef. | Std. Err. | P>z |
|---|---|---|---|
| Age | 0.022 | 0.019 | 0.216 |
| Labour | 1.023*** | 0.333 | 0.002 |
| Donkey cart | 0.402 | 0.563 | 0.475 |
| Transhumance | -1.786*** | 0.730 | 0.014 |
| Poor infrastructure | 0.355 | 0.494 | 0.473 |
| Education | -2.064** | 0.921 | 0.025 |
| Yield of cotton (kg/ha) | 0.002 | 0.001 | 0.176 |
| Origin | -1.534 | 1.045 | 0.142 |
| Soil fertility | -0.753 | 0.599 | 0.209 |
| Ln farm income | -0.079 | 0.148 | 0.599 |
| Frequency of weeding | -1.110** | 0.517 | 0.020 |
| Extension services | 0.436 | 0.768 | 0.570 |
| High input prices | 0.241 | 0.547 | 0.660 |
| Ln off farm income | -0.007 | 0.051 | 0.886 |
| Access to credit | -0.187 | 0.617 | 0.762 |
| Constant | 1.032 | 2.649 | 0.697 |
| Number of plot | 126 | | |
| LR chi2(15) | 44.29 | | |
| Prob > chi2 | 0.000 | | |
| Log likelihood | -59.370 | | |
| Pseudo R2 | 0.272 | | |

Note: **, *** significant at 5 %, 1 % level respectively

Table 28: Marginal effects of organic matter practices

| | dy/dx | Std. Err. | P>z |
|---|---|---|---|
| Age | 0.004 | 0.004 | 0.216 |
| Labour | 0.198*** | 0.056 | 0.000 |
| Donkey cart | 0.078 | 0.108 | 0.473 |
| Transhumance | -0.398** | 0.162 | 0.014 |
| Infrastructure | 0.067 | 0.092 | 0.463 |
| Education | -0.472*** | 0.191 | 0.014 |
| Yield of cotton (kg/ha) | 0.000 | 0.000 | 0.175 |
| Origin | -0.210** | 0.091 | 0.021 |
| Soil fertility | -0.132 | 0.094 | 0.159 |
| Ln farm income | -0.015 | 0.029 | 0.597 |
| Frequency of weeding | -0.232** | 0.100 | 0.021 |
| Extension services | 0.078 | 0.125 | 0.533 |
| High input prices | 0.048 | 0.112 | 0.669 |
| Ln off farm income | -0.001 | 0.010 | 0.886 |
| Access to credit | -0.037 | 0.125 | 0.767 |

Note: *, ** and *** significant at 10%, 5% and 1% level respectively

**4.17.2. Maize production technology assessment**

The MVP model is estimated using the maximum likelihood method on maize plots level observations. The Wald test ( $\chi^2$(44) =92.02, p=0.000)) is significant at 1 % level which indicates that the hypothesis of all regression coefficient in each equation are jointly equal to zero is rejected. The results of likelihood ratio test in the model was (LR $\chi^2$(6) = 72.0045, p =0.000)) indicated the null that the independence among technologies choice decision ( $\rho 21 = \rho 31 = \rho 41 = \rho = 32 = \rho = 42 = \rho 43 = 0$ ) is rejected at 1% significant level. There are differences in technology adoption among smallholder famers in cotton production of Mali. Based on the MVP model results in Table 29, some of the variables were significant for more than one technology adoption while one variable was significant in only one technology adoption.

Oxen ownership was negative and statistically significant at 10% level of significance and determines adoption of plough and sowing in the study area. This implies that farmers with few numbers of oxen are less likely to adopt those practices. This is explained by the multiple tasks performed by oxen in farming. In the past, the company in the charge of cotton production offered oxen to the farmers as credit in order to allow them to grow cotton. Nowadays, the company no longer considers this kind of credit. On the other hand, lack of oxen contributes to the reduction of area cultivated and results to decreasing of cash generating activities.

There was a positive and significant relationship between access to agricultural credit and ploughing as well as hand sowing at 1% level of significance. Farmers that practiced ploughing and hand sowing were more likely to access agricultural credit in order to move out of the hand sowing. Credit constraint is a major factor for farmers to adopt certain agricultural practices in rural areas. On the other hand, access to agricultural credit improves the livelihood of farmers and allows them to allocate a larger land size for maize cropping. Additionally, it contributes to food security, alleviation of poverty and malnutrition. Mbata (2001) and Theriault *et al*. (2017) argued that access to agricultural credit affects positively the practice of agricultural technology adoption by smallholder farmers mainly where there is liquidity constraint. Access to agricultural credit is essential for assuring productivity.

Agricultural tools (plough, carts, sowing) were positive and statistically significant at 5% level of significance for organic matter, ploughing and hand sowing and negatively influenced the practice of ploughing and sowing at 5% level of significance. Farmers with agricultural tools are more likely to practice organic matter production, ploughing and hand sowing. For instance, organic matter production requires transportation of crop residues from the field by the oxen (cattle) and vice versa therefore a cart is an important tool for adoption of organic matter production. A farmer who lacks agricultural tools is discouraged from practicing these agricultural technologies. Concerning, ploughing and hand sowing, farmers were more likely to increase their agricultural tools in order to be able to cultivate larger plot size at the time. Farmers with bigger numbers of agricultural tools were less likely to adopt the practice of ploughing and sowing. This is unexpected sign, since the availability of agricultural tools increases the cultivated area of land. This could be explained by farmers having old agricultural tools that need replacement. These draught tools and animal power constitute the main tools for the development in agriculture in Southern Mali.

Plot size (hectare) influenced negatively the practice of improved seed, ploughing and hand sowing, and influence positively the practice of ploughing and sowing at 1% significance level. Farmers with larger plot sizes for maize are less likely to practice improved seed. This is attributed to the availability of cash at farmer’s level to afford it at the beginning of rain season in Southern-Mali. It is also explained by the quantity demanded of improved seed per hectare which is not economical to cover the allocated land size of maize. Less practice of improved seed results in the decrease of farmers output in terms of maize yield per hectare. Farmers who adopt the technology ploughing and hand sowing are less likely to expand their plot size. This is explained by the lack of certain tools of agricultural equipment such as sower and limited by the number of oxen ownership. In addition, hand sowing utilizes work force which increases the time of sowing on large land size and results to the decreasing of land size. This finding is in line with Nigussie *et al*. (2017) who found out a negative relationship on the practice of *fanya juu*, stone-faced soil bund and traditional stone bund technology in North western Ethiopia. Farmers with larger plot size are more likely to adopt ploughing and sowing. This implies that well equipped farmers can expand the cultivated area. In addition, the farmers with larger land size and own complete agricultural tools (plough, sower, oxen, and carts) are larger families with a higher availability of labour. The is consistent with Ahmed *et al*.(2017) and Ali and Erenstein (2017) in Ethiopia and Pakistan who argued that farmers with large land size own are more likely to try out agricultural technology practice

The frequency of weeding was positively associated to practice of ploughing and hand sowing and negatively associated with practice of plough and sowing. Farmers who adopt ploughing and hand sowing are more likely to weed the plot at least twice before harvesting. Ploughing and hand sowing requires lot of labour for weeding. As for ploughing and sowing, farmers are less likely to weed twice the plot. This is attributed to the ploughing system and requires less labour.

The coefficient of land ownership was positive and statistically significant at 5% levels of significance. Farmers who are landowners were likely to adopt organic matter production. In the study area there is no rental land which is limited to certain investment on it. This implies that land ownership increases the practice of agriculture technologies. The result is in line with Fosu-mensah *et al*. (2012); Kassie *et al*. (2015) and Iheke and Agodike (2016) who found a positive correlation between land ownership and agricultural technology practice in SSA.

Off farm income had a negative and significant relationship with ploughing and hand sowing at 5% levels of significance. Farmers who were engaged in off farm activities were less likely to adopt ploughing and hand sowing technology. This is explained by the level of income from non-farm that discourages farmers to engage in agricultural production and practice of new technology. The result is similar to the finding of Verkaart *et al*. (2017) who found a negative association to the practice of chickpea practice in Ethiopia. It was also positive and significant with plough and sowing at 5% levels. In other words, off income increases the practice of plough and sowing agricultural technology. Savadogo and Pietola (1998), argued off-farm income was an essential determinant of agricultural productivity and its intensification mainly linked to animal power.

Table 29: Determinants of agricultural technology practices for maize (Multivariate probit)

| Variables | Improved seed | Organic matter | Plough +hand sowing | Plough+ sowing |
|---|---|---|---|---|
| | Coef | Coef | Coef | Coef |
| Age | 0.004 | 0.002 | 0.005 | 0.000 |
| Labour | 0.025 | 0.073 | 0.105 | -0.161 |
| Oxenown | -0.139 | -0.012 | 0.041 | -0.094 |
| Plot size (ha) | -0.806*** | -0.222 | -0.723*** | 0.483*** |
| AgriTools | 0.132 | 0.138** | 0.164** | -0.160** |
| Extension | -0.256 | -0.178 | 0.229 | -0.138 |
| Accesscredit | 0.031 | 0.039 | 0.875*** | -0.391 |
| Freq.Weeding | 0.228 | -0.410 | 0.975*** | -0.927*** |
| Landowne | 0.541 | 0.878** | 0.303 | -0.409 |
| Education | 0.413 | -0.131 | 0.166 | -0.288 |
| Offfarmincom | 0.014 | 0.001 | -0.070** | 0.049* |
| Constant | -1.234 | -1.110 | -1.439 | 2.265*** |
| Rho2 | | | | |
| Rho3 | | | | |
| Rho4 | | | | |

Likelihood ration test of rho=21=rho=31=rho=41=rho=32= rho=42 = rho=43=0.000

Chi2 (6) =72.0045

Prob>chi2=0.000

Note: *,**,***, significant at 10% , 5 % and 1% level respectively

**4.17.3. Agricultural technology practices for millet cropping (Bivariate probit)**

The Table 30 reported the results of bivariate probit estimation effects for ploughing and sowing, and inorganic fertilizer practice for smallholder farmers in cotton growing zone of Mali. The Wald test ($\chi^2(18) = 29.76$, p=0.039)) is significant at 5% level of probability.

This indicates that the hypothesis that all regression coefficient in each equation are jointly equal to zero is rejected.

In the model, the explanatory variables are family characteristics, institutions factors and plot size. Some of the explanatory variables were significant on the two agricultural technologies and some were significant on one agricultural technology practice. The age of family head was negative and statistically significant on ploughing and sowing technology at 10% levels of probability. The negative relationship shows that older smallholder farmers were less likely to practice ploughing and sowing. This may be because the size of grain of millet and the rate of germination is low when the sowing was done with sower. Smallholder older farmers preferred ploughing and hand sowing than the use of sower or planter.

Nowadays, younger farmers prefer ploughing and sowing due to less work with animal power for both activities. Older smallholder famers are more conservative to change their agricultural practices to ploughing and mechanic sowing which causes non-germination of seeds. This is consistent with Chirwa (2005) and Ogada *et al*. (2014) who reported a negative relationship between age a practice of fertilizer and hybrid seeds in Malawi and Kenya and inconsistent with Amsalu and Graaff (2006).

The coefficient of family size was positive and statistically significant to the practice of plough and negatively associated with inorganic fertilizer at 1% level of significance. Larger family sizes were more likely to adopt ploughing and sowing and less likely to adopt inorganic fertilizer. Family size plays an important role for technology practice of any particular farm practices. As for inorganic fertilizer, the decreasing practice is explained by the larger land size allocated by larger families and difficulty in covering all land sizes under crops such as cotton, maize, millet and sorghum. This is in line with (Bekele and Drake, 2003) and (Amsalu and Graaff, 2006).

Agricultural tools are an important determinant for technology practice by smallholder farmers. Agricultural tools are important determinants for technology practice by smallholder farmers. With important tools of agricultural equipment, smallholder farmers are more likely to adopt inorganic fertilizer. In the other hand, this is explained in the form of family size which is correlated with number of agricultural tools. The coefficient of education level was negative and statistically significant associated with practice of ploughing and sowing and positively related to the practice of inorganic fertilizer at 1% level of significance. The unexpected sign for ploughing and mechanic sowing could be because education level has been recognized to play an active role in the practice of agricultural technologies. Smallholder farmers with high level of education were more likely to adopt inorganic fertilizer. The finding is similar with Rahman (2001) who argued education is key element for agricultural technology practice by smallholder farmers.

Access to agricultural extension services was significant and positively related to the practice of inorganic fertilizer at 1% level of significance. Smallholder farmers with access to extension services were more likely to adopt the use of inorganic fertilizer. This result indicates that extension agents play a huge link for transferring agricultural technologies, advising and informing at the farmer's levels. They train farmers and strengthen their skill through training on good agricultural practices. This in line with Pratt and Wingenbach (2016) in practice of green manure and cover crops technology in Uruguay and inconsistent with (Rahman and Chima, 2015).

Plot size of millet was positively significant and related to the practice of inorganic fertilizer at 10% level of significance. Farmers with larger plot size were more likely to adopt inorganic fertilizer technology. Additionally, farmers emphasized food security by increasing the use of inorganic matter. Similarly the result is consist with previous study of Kassie *et al.*(2011); Kassie *et al*. (2014) and Ogada *et al*. (2014) fund out the positive association between landholding and agricultural technology adoption. The coefficient of high cost of agricultural inputs applied was negatively associated with practice of inorganic fertilizer applied at 10% levels of significance. With high cost of inputs, farmers are less likely to adopt inorganic fertilizer which discourages farmers to diversify the cropping systems and results to low output of crop.

Table 30: Determinants of agricultural technology practices for millet (Bivariate probit)

| Explanatory variables | Plough + sowing | | Inorganic fertilizer | |
|---|---|---|---|---|
| | Coef. | Std. Err. | Coef. | Std. Err. |
| Age family head | -0.072* | 0.033 | 0.004 | 0.016 |
| Family size | 0.094*** | 0.031 | -0.040*** | 0.018 |
| Oxen ownership | -0.279 | 0.365 | -0.149 | 0.114 |
| Agri tools | -0.408 | 0.346 | 0.422** | 0.197 |
| Education | -2.784*** | 0.932 | 1.420*** | 0.516 |
| Access to credit | -0.465 | 0.804 | -0.151 | 0.525 |
| Extension | -0.489 | 0.775 | 1.853*** | 0.636 |
| Plot size (ha) | -0.141 | 0.340 | 0.242* | 0.144 |
| High cost Agri inputs | 1.246 | 0.795 | -0.952* | 0.541 |
| Constant | 4.407*** | 1.744 | -1.952** | 1.023 |
| Number of plots | 63 | | | |
| Wald chi2(18) | 29.76 | | | |
| Prob > chi2 | 0.0398 | | | |
| Log likelihood | 37.3249 | | | |

Note: *,**,***, significant at 10%, 5 % and 1% level respectively

#### 4.17.4. Agricultural technology practices practice for Sorghum

Table 31 presents the results of bivariate probit estimation of ploughing and sowing and inorganic fertilizer technology practice by smallholder farmers in cotton production zone of Mali. The Wald test ( $\chi^2$(22) =37.66, p=0.02)) significant at 5% levels of probability. This shows that the hypothesis of all regression coefficient in each equation are jointly equal to zero is rejected. The explanatory variables included in the model are socioeconomic factors and institutional factors.

The coefficient of the age of family head was negatively associated with ploughing and sowing technology at 5% of significance levels. This implies that practice of ploughing and sowing technology decreased when age increased. Older smallholder farmers tend to rely on hand sowing with better rate of germination of seed than sower technique. However, younger farmers practice easily ploughing and sowing due to less physical effort provide for doing the work. All procedure involves animal power and less restricting. This is inconsistent with Langyintuo and Mungoma (2008); Alabi *et al.* (2014) and Sharma and Singh (2015) found that age had a positive effect on agricultural technology adoption.

The coefficient of oxen ownership was negatively and statistically significant associated with of inorganic fertilizer technique at 1% level of significance. Smallholder farmers with oxen were less likely to adopt inorganic fertilizer technology in the study area. This is explained by the quantity of organic matter produced per herd size and applied under crops. The important quantity of organic matter produced within family contributes to reduce the quantity of inorganic fertilizer applied per hectare. Farmers adopt organic matter production in order to divert the inputs contracted for cotton and maize to use it under non-subsidy cerealss in terms of inputs.

The coefficient of agricultural tools was positive and statistically significant associated with practice of inorganic fertilizer at 1% level of significance. Smallholder farmers with important agricultural tools were more likely to practice inorganic fertilizer technology. On the other hand, practice of technology depends on family endowment. The availability of agricultural tools in the families is more receptive to new agricultural technique.

Education level had a positive and significant relationship on decision to adopt inorganic fertilizer at 1% level of significance. More educated smallholder farmers were more likely to engage in new farming technology and easily handled it. In addition, higher level of education determines smallholder farmer's decision to adopt agricultural technologies. The result is in line with Nkamleu and Adesina (2000) who reported that high level of education in application of chemical fertilizer has a positive relationship to the decision of the use of chemical fertilizer in Cameroon.

Concerning, the coefficient of access to agricultural inputs credit was negatively and statistically significant to the practice of inorganic fertilizer at 5% levels and determines the level of agricultural technology adoption. This implies that farmers who have not accessed agricultural inputs credit were less likely to adopt inorganic fertilizer technique. This is explained by the nature of these cereals (millet and sorghum) where they are not supported by inputs subsidy in the study. This results to the low output of these two cereals in this area. This is consistent with Alabi *et al*.(2014) found that farmers invest the credit to non-farming than agricultural purpose and inconsistent with (Asfaw *et al*., 2012).

The coefficient of sorghum plot size was positively associated with inorganic fertilizer and significant at 5% levels of significance. With larger size of land, farmers were more likely to adopt agricultural technologies to improve productivity. High cost of agricultural inputs was negatively associated with farmer's decision to adopt inorganic fertilizer technology at 5% levels of probability. Regarding high price of inputs, farmers were less likely to adopt the use of inorganic fertilization. This implies that the higher price of agricultural inputs reduces the probability of inorganic fertilizer adoption. In other words, it discourages farmers to undertake any form of agricultural enterprises.

Table 31: Determinants of agricultural technology practices for sorghum (Bivariate regression)

| Variable | Plough + sowing | | Inorganic fertilizer | |
|---|---|---|---|---|
| | Coef. | Std. Err. | Coef. | Std. Err. |
| Age family head | -0.038** | 0.019 | 0.009 | 0.024 |
| Family size | 0.019 | 0.014 | -0.023 | 0.020 |
| Oxen ownership | -0.134 | 0.180 | -0.631*** | 0.222 |
| Agri. tools | -0.128 | 0.142 | 0.692*** | 0.201 |
| Education | -0.364 | 0.496 | 1.585*** | 0.692 |
| Access to credit | 0.310 | 0.509 | -1.451** | 0.769 |
| Extension | 0.486 | 0.642 | -0.753 | 1.075 |
| Plot size (ha) | 0.408 | 0.372 | 0.458** | 0.410 |
| Hcostagriinput | 0.867 | 0.652 | -1.446** | 0.662 |
| Farm income | 0.028 | 0.067 | -0.061 | 0.116 |
| Off farm income | -0.035 | 0.040 | 0.075 | 0.053 |
| Constant | 0.830 | 1.167 | -2.254 | 1.846 |
| Number of plot | 57 | | | |
| Wald chi2(22) | 37.66 | | | |
| Log likelihood | -40.342 | | | |
| Prob > chi2 | 0.020 | | | |

Note: **,*** significant at 5% and 1 % level respectively

### 4.18. Comparison of main crops outputs and inputs applied by village

#### 4.18.1. Comparison Cotton output and inputs applied by village

The comparison of output yield per hectare and main inputs used such as NPK and Urea per hectare for cotton production among tree villages are presented in Figure 15. The yields per hectare were 1046 kg/ha; 1138 kg/ha and 1146 kg/ha for Beguene in the old basin production, Nafegue in the sub-humid part and Ziguena in the central respectively. The central and sub-humid zones recorded high yielding per hectare than the old basin production. This is explained by over cultivation the land under cotton, thereby more pressure on natural resources which results in low fertility of soil. On the other hand, farmers in old basin allocate small size of land area under cotton compared to the two last villages. On average old basin (Beguena) had 2.83 ha, Nafegue 4.14 ha and Ziguena 7.29 ha. As for NPK used per hectare, was 126 kg/ha in sub-humid (Nafegue), 140 kg/ha in old basin (Beguena) and 152 kg/ha in the central (Ziguena). These quantities of NPK applied in the first two villages were below the normal quantity recommended. The normal quantity allocate per hectare for NPK cotton is 150 kg/ha delivered by the company in charge of cotton cropping through producer's cotton cooperative. The difference among villages in terms of kg/ha applied is attributed to farming practices. Similarly, quantity of urea applied per hectare was 50 kg/ha in sub-humid, 53 kg/ha in central and 56 kg/ha in old basin respectively. This quantity was almost in line with quantity of urea recommended by the research and extension services which is 50 kg/ha.

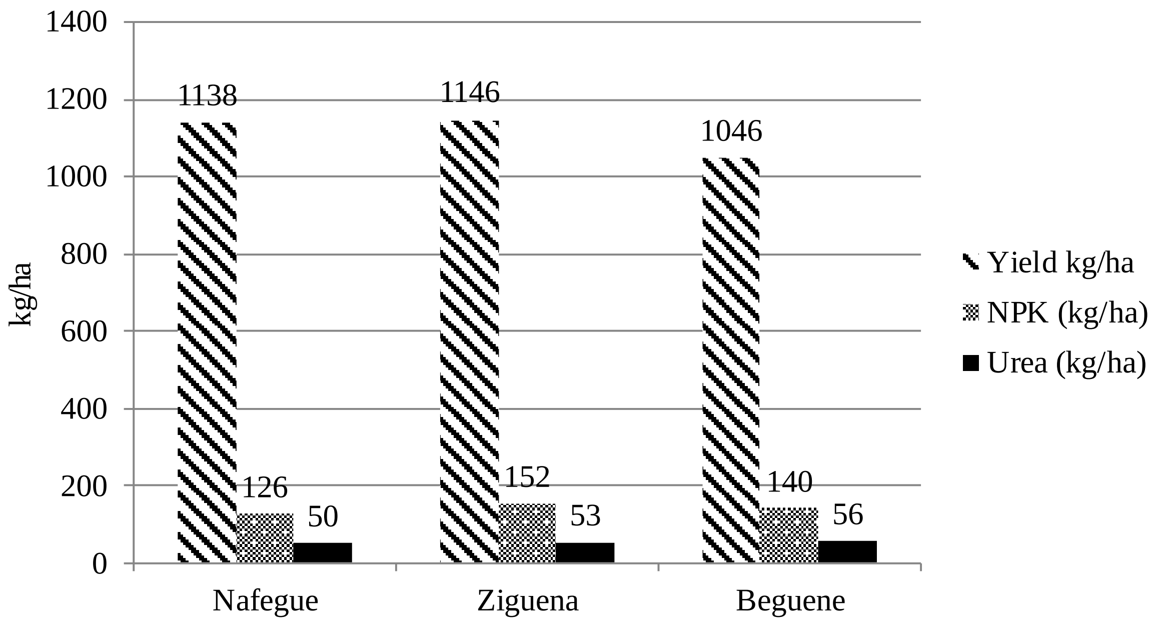


Figure 15: Output and inputs (NPK ad Urea) of cotton per hectare and by village

**4.18.2. Maize output, NPK and Urea applied per kg and per village**

Figure 16 shows the different outputs of maize and main inputs (*complex cereals* and urea per hectare) used under maize among different villages. The maize yield varies across villages from 1668 kg/ha in Beguene, 1807 kg/ha in Nafegue and 2144 kg/ha in Ziguene. This low yield recorded in each village is attributed by the low use of improved seed where around 64 % farmers used it and the other farmers re-use the same seed for new planting season. Moreover, low yield of maize is also explained by low use of the main agricultural inputs NPK and urea applied.

The quantity of NPK per hectare was 95 kg/ha in Ziguena, 100 /ha in Nafegue and 132 kg/ha in Beguene. On the same, the quantity of urea applied per hectare varied among villages. Thus, in sub-humid the quantity applied was 56 kg/ha, 64 kg/ha in old basin and 84 kg/ha in central. All main inputs used under maize were low compared to the quantity recommended by the researchers and extension services which is 150 kg/ha for urea and 100 kg/ha for NPK cereals implying farmers are not sufficiently using these inputs. This abnormal use of the input is attributed to the diversion to the crops which are not subsidized such as millet, sorghum among others. These factors explain the low yields of maize across the study area.

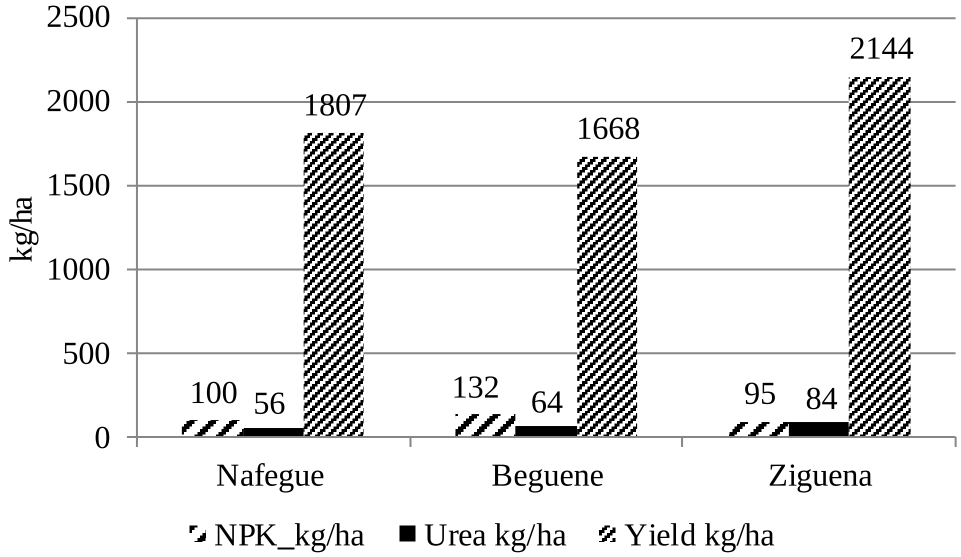


Figure 16: Output maize and inputs (NPK and Urea) per hectare and by village

**4.18.3. Comparison of millet production and inputs used by village**

The production of millet output and main inputs used per village is presented in Figure 17: Output millet and inputs (NPK and Urea) per **hectare and by village** The yield per hectare was 619 kg/ha in Ziguena part, 675 kg/ha in Nafegue and 859 kg/ha in Beguene. Old basin zone of cotton growing zone had recorded the best yield per hectare due to large land area under millet. On average farmers in Beguene, allocate 3.29 ha for millet as opposed the two last villages which on average these farmers allocate 1.11 and 1 ha for Ziguena and Nafegue part of cotton growing zone respectively. The inputs such as NPK and urea used under millet are very little compared to the quantity recommended by the research and extension services which is 100 kg/ha and 50 kg/ha for NPK and urea respectively. This is explained by non-subsidy of these inputs and smallholder farmers are limited by cash constraints to afford the inputs needed. This fact shows the small or null quantity of main fertilizer used under the millet and sorghum.

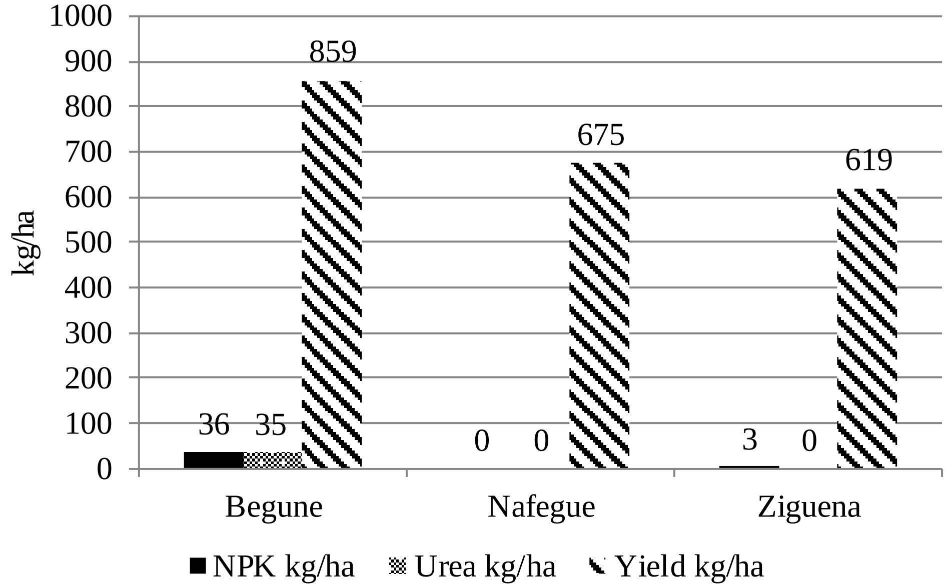


Figure 17: Output millet and inputs (NPK and Urea) per hectare and by village

**4.18.4. Production of sorghum output and NPK and Urea applied by village**

The results of sorghum production in cotton growing zone in terms of yield per hectare and main fertilizer (NPK and Urea) used are reported in the Figure 18. The yield per hectare was 563kg/ha in Beguene, 624 kg/ha in Nafegue and 693 kg/ha in Ziguena. This variability is explained not only by the land area under sorghum but also by the type of soil of planting area. In general, farmers allocate the marginal type of soil for sorghum planting in the study area. The average land area under sorghum was 0.85 ha in Nafegue zone and 1.34 and 1.35 ha in Ziguena and Beguene respectively. In addition, sorghum had insufficient or null intake of inorganic fertilizer due to their accessibility by farmers. Even though farmers belong to the cooperative of cotton producers, to access inorganic fertilizer for millet and sorghum had not been considered in Southern-Mali. The quantity of inorganic fertilizer applied such as NPK and urea was null in sub humid zone, 2 kg/ha for both in central and 24 and 34 in old basin of NPK and urea respectively. These quantities are below the quantities recommended by the research and extension services which is 100 kg/ha and 50 kg/ha for NPK and urea respectively.

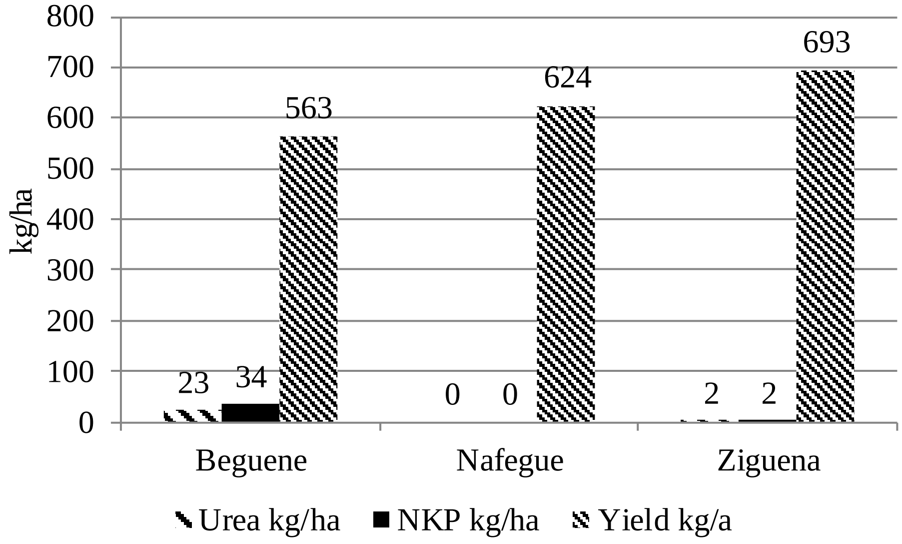


Figure 18: Output sorghum and inputs (NPK and Urea) per hectare and by village

**4.18.5. Comparison of Gross Margin (GM) across cropping systems**

The Gross Margin (GM) for main cropping systems was computed which is measured in terms of the difference between the total revenue and the total variables cost Figure 19. Across four main crops cultivated is the gap between cash crop (cotton) and cereals (maize, millet and sorghum). The GM for cotton was about -57,278 FCFA per hectare, which is explained by the intensification in terms of inputs used for its production such as (labour, chemical inputs) despite the increased farm gate price of cotton kilogram (250 FCFA per kg) and land size in planting 2016-2017. The GM for maize occupied the first rank among cereals which was 110,782 FCFA followed by sorghum with 69,398 FCFA per hectare and millet on average 52,318 FCFA per hectare farmed. This is due to the importance in allocation of land size for maize and it constitutes the staple food in the study area. It is also supported by inputs subsidies through cotton cropping than the two last cereals. The feeble contribution of sorghum and millet to the farming income is due to their yield per hectare and important is their low farm gate prices that is 125 FCFA and 150 FCFA for sorghum and millet respectively.

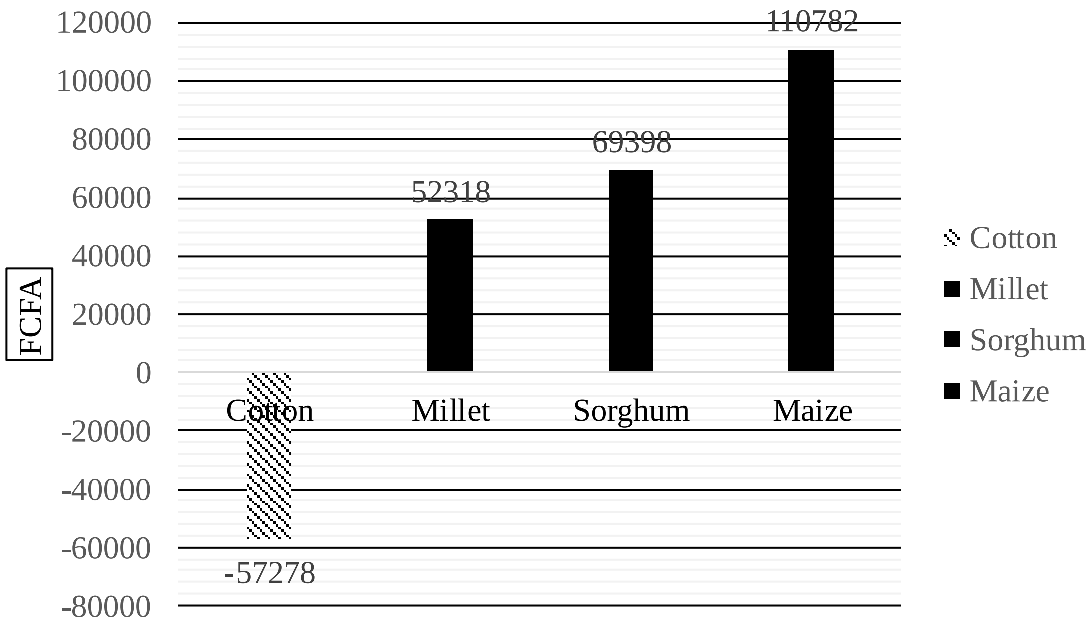


Figure 19: Gross margin across four crops in the study area

### 4.19. Simulation options of Gross Margins (GM) of five types of farming families under *Olympe*

#### 4.19.1. Increased cotton land size and inputs subsidy

Figure 20 shows the behaviour of GM of the five types Table 13 of farming families in response to a 10% increase in land size allocated to cotton and input subsidies. The farming family types have different GM and fluctuate over the ten years. This implies that the five types of farming family differ in characteristics such as resource endowment. The results indicate that Type2 farming families have better GM over the ten years compared to the other four types. This is explained by the importance of cotton in the rotation systems. The Type2 farming families have 44% of their cultivated land area under cotton. However, at the beginning of simulation, 2016-2019, GM for the Type2 decreases and then catches up in 2020 into the long-run. The decrease in GM in the initial years is attributed to the availability of workers at the beginning of planting season. In addition, labour at the starting cropping season determines the output of cotton per hectare. In other words, applying chemical and organic fertilizer, weeding and pesticide application frequency, crop rotations, and climate conditions contribute to the declining of cotton output and income.

Despite having an average family size of 54 people and relatively well-endowed with resources, the Type1 farming families' GM almost remains constant along the simulation period. This is attributed to the share of cotton in the rotation system which was about 33%. In addition, Type1 farming families emphasize food security as a result of many mouths to feed. Low GM pushes Type1 farmers to participate in non-farm income generation activities and sell of crop produce to cover family expenditure. Types4 and Type5 farming families have sustainable GM growth that tend to improve in the long-run. However, the share of cotton in crop rotation differs for each type of household with 11% and 25% of the cropland under cotton for Type5 and Type4 respectively. This sustainable trend in GM is explained by the optimal use of chemical inputs and organic matter. Despite having a 35% share of land in crop rotation under cotton, the Type3 farming families have the lowest GM from the beginning which increases in the course of years. The low GM is explained by the output of cotton per hectare. In other words, the output of cotton depends on farming practices such planting date, frequency of weeding, and the frequency of chemical and organic fertilizer and pesticide application among others.

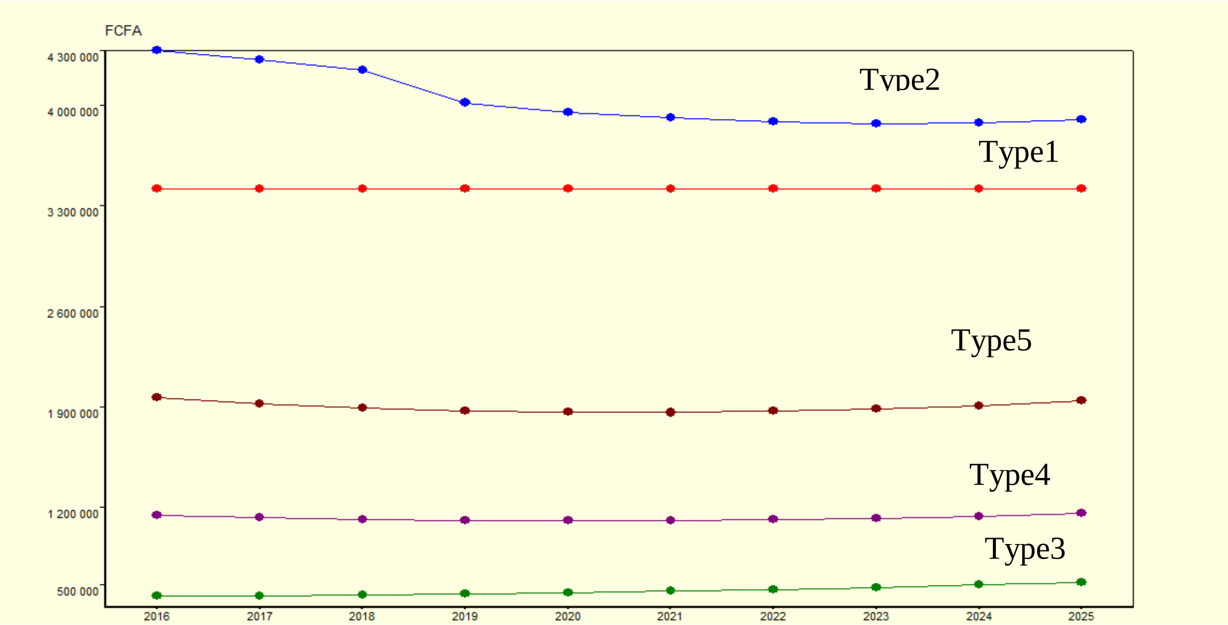


Figure 20: Increasing cotton land size and inputs subsidies

#### 4.19.2. Increased cotton land size without inputs subsidy

Figure 21 shows the trend in GM of the five types of farming families with an increased allocation of land to cotton but without input subsidy. Results indicate that the GM decreases due to the effect of inputs prices. However, in the first three years, the Type2 farmers still generate income from cotton. In the long-run, the income declines and then maintains constant trend. This implies that without subsidy of agricultural inputs farmers manage and efficiently utilize the available set of inputs. It can also be explained by the importance of cotton farming to the livelihoods of families in the cotton production zones in Mali. Concerning the Type1 farming households, although inferior to Type2 in terms of land area allocated to cotton, that is 33% and 44% respectively. The constant trend of GM is could be explained by the effectiveness use of inputs. In the long run, the GM are almost at the same level for both Type1 and Type 2 farming families. The GM from cotton declines, compelling farmers to engage in alternative income generating activities.

The GM for the Type4 and Type5 farming families show almost the same trend during the ten years. These two types of farming families probably use similar agricultural practices to cope with the changes that occur without input subsidy. The GM remains constant with an increase in the size of land allocated to cotton production by Type4 to Type5 farming families. This is explained by the technical itinerary (ploughing, planting date, weeding and use of inputs) of cotton production undertaken by the two types of farming families. Overall, the trend in the GM for Type1, Type2, Type4 and Type5 farming families is due to increase in land size under cotton and application of organic matter and technical itinerary of cotton. The non-subsidy of agricultural inputs has important influence on the GM of Type4 and Type5 farming families. However, the share of cotton in crop rotation is about 25% and 11%, respectively, of the total cultivated land area. This unprecedented increasing in GM is could be explained by an increase in the output of cotton per hectare which is influenced by agricultural technology. For the Type3 farmers, the GM plummets falls as the land area allocated to cotton increases. In the long-run, Type3 farmers give up cotton cropping due to the increasingly decreased GM. This constant decreased GM is explained by the efficient use of availability agricultural technology and practices. Although Type3 farmers had 35% of the land size allocated to cotton and applied only 790 kg per hectare of organic matter. In addition, work organization or planning for cropping season influences the output of cotton due to individual work rather than common pool. This Type probably sales cereals to overcome daily family expenditure. On the other hand, they undertake several non-farm income generation activities.

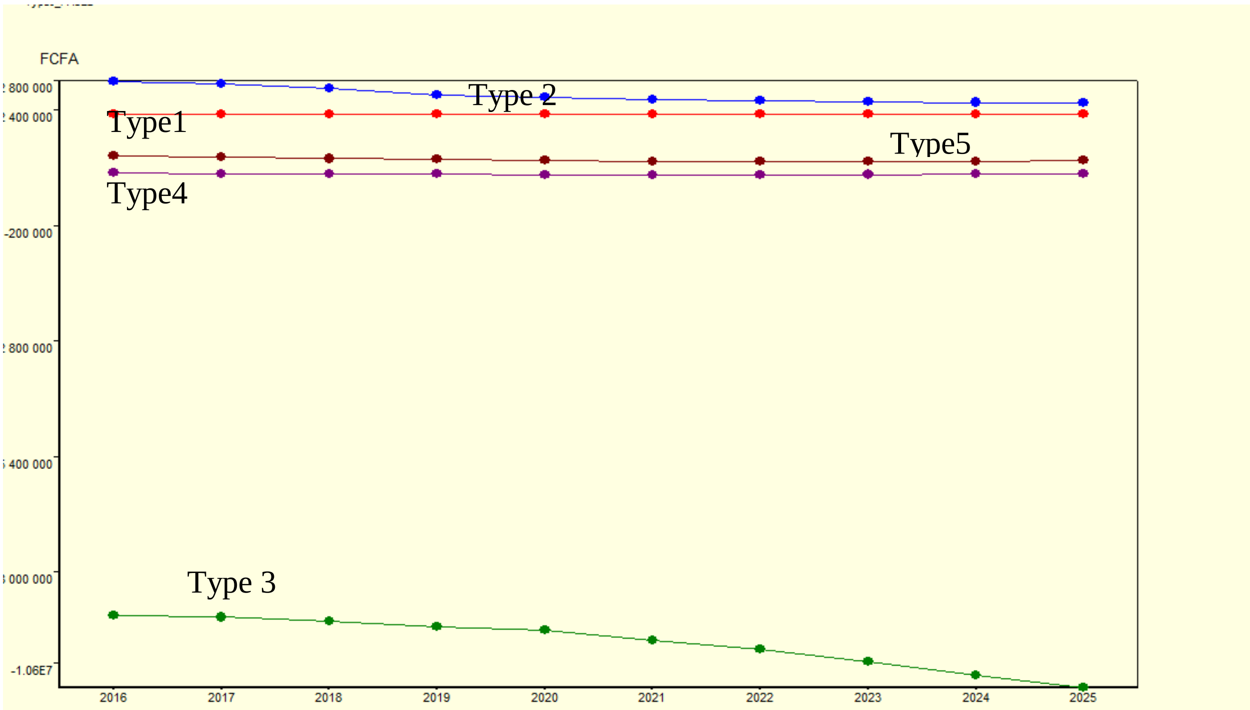

Figure 21: Land size under cotton increased without subsidy

### 4.19.3. Decreased cotton land size without inputs subsidy

The trend in GM for the five types of farming families when land allocated to cotton production decreases and with non-subsidy of inputs is shown in Figure 22. The five types of farming families respond differently to the two changes. The GM of Type2 farming families decline from 2016 to 2021 then catches up later and remains constant in the long-run. The decline of GM in the first five years is due an increase in prices of agricultural inputs used for cotton production. The constant GM thereafter is explained by the utilization of other agricultural practices and efficient use of the available set of inputs. In addition, small land size allows farmers to intensify crop production and follow chemical fertilizer and pesticide application calendar. Turning to the Type1 farming families, the decrease in the size of land allocated to cotton positively influences the level of GM. The decrease in size of land under cotton permits these farmers to improve their GM in the long-run. The improvement in GM in the ten years for this type of farming families is explained by the efficiency associated with limited use of agricultural inputs.

The GM for Types4 and Type5 farming families present almost the same trajectory even though Type 5 has a higher GM. The GM slightly drops at the beginning and then evens thereafter. As opposed to Type4 farmers, the GM for the Type5 farming families remain constant across the years. On other hand, the small size of land under cotton and lack of access to subsidized inputs permit farmers to apply the inputs provided by the company only on cotton and not any other crop. For Type3 farmers, the GM are low from 2016 to 2021 and then evens, leading to increase in GM in the long-run. This positive variation in GM is could be explained by utilization of improved agricultural technologies. These practices lead to higher output per hectare, allowing additional income after input credit deduction.

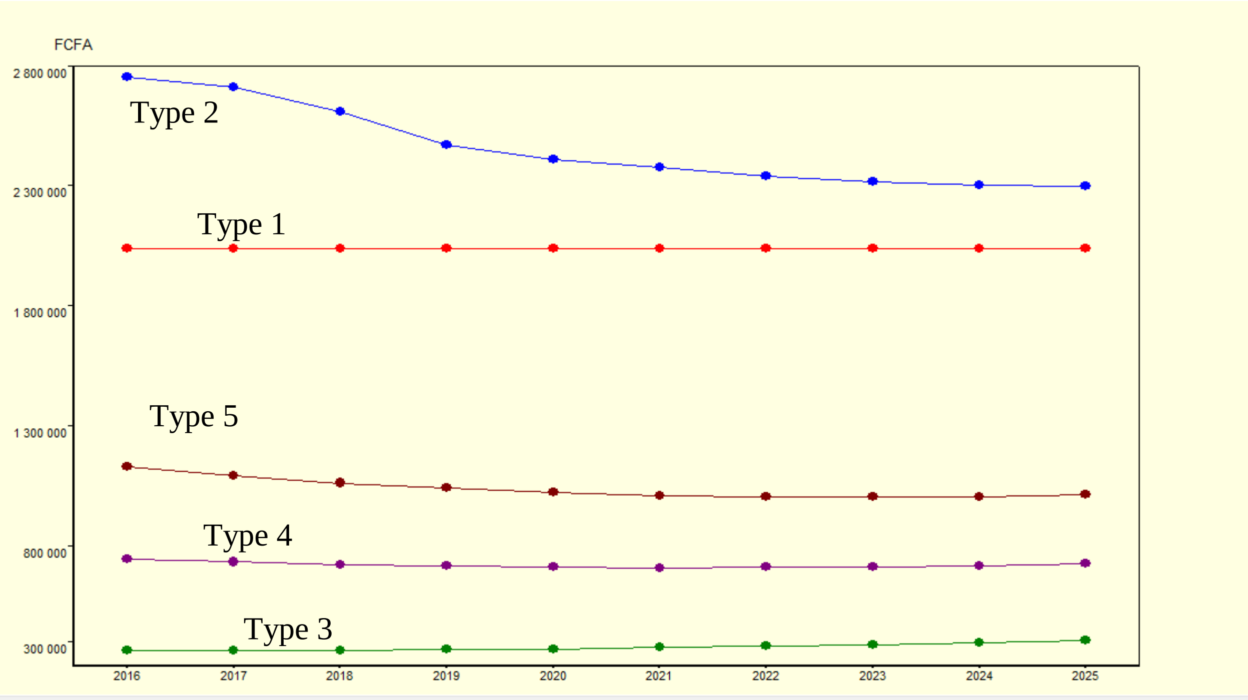


Figure 22: Land size under cotton decreased without inputs subsidy

**4.20 Cotton as link between cereals production and livestock system**

The study is not based on cotton farming but it constitutes the support and development of other production systems and diversification strategies of that zone's population. Through, cotton most of agricultural farming families are equipped and more than 75% possess adequate equipment in draught animal power and plough and cotton occupy 32% of crops system (CMDT, 2005). In Southern Mali, cotton earnings have been used to invest in livestock, providing draught animals and breeding animals. Furthermore, cotton production leads to socio-economic and infrastructural development in the cotton producing zone. The developments include the setting up new schools, health facilities and construction of roads among others. Farmers are trained in the local languages on good farming practices. Serra (2012) argues that 52.17% of farmers increased sizes of land under cotton to enhance revenues. Furthermore, Serra (2012) opines that there a 50% positive background effects of fertilizer use on cotton that is also beneficial to cereal crops. This is associated with the rotation of cotton and cereals coupled with livestock production.

# CHAPTER FIVE
# CONCLUSION AND RECOMMENDATION

## 5.1. Conclusions

Smallholder farmers' dynamics were established and classified into five types using structured and functional variables. Type 1 represented 14 % of the sampled agricultural farming families. Most of type A in CMDT typology has tended to change to another type by being endowed with large herd size, more draught power, draught tools and more labour. Agricultural farming families that constitute Type2 represented 28 % of the sampled families. Some of type A are also represented in this category as they move towards large families that are well equipped in terms of herd size, draught power, draught tools and cultivated area. Type3 is the most important and the most dominant in the cotton growing areas. It represented about 28 % of smallholder farmers. Former type A, B, and C are represented in this type of smallholder farmer type. On the other hand, these types tend to move towards medium agricultural farming families that are well endowed just like type A in the CMDT typology. They allocate 35 % and 44 % of their land to cotton and cereals production respectively and possessing important herd sizes. Type4 represents 19 % of the sampled agricultural farming households. It overtakes former type A in terms of the number of draught tools, draught power, herd size and the area allocated to cereals. The last type, Type5, represents 11 % of the farming families. It is equivalent to CMDT's type C.

They operate on incomplete tools and have some livestock. It is composed of the young families and families that migrate into the village. Type 5 families attempt to endow themselves and are not market oriented. Cereals represent 76 % of crop rotation. However, the quantity of organic matter produced by all types is very low despite the availability of technologies to produce organic matter in large quantities and good quality. About 67 % of smallholder farmers in cotton producing areas in Southern Mali keep livestock primarily for animal power. Milk production and revenue follow at 14 and 13 % respectively. Lastly, only 6 % of smallholder farmers keep livestock for organic matter production.

Findings on drivers of multiple sources of income generating activities among farming families, the results indicate that there is substantial complementarity and substitutability among sources of income. Correlation matrix analysis showed positive and negative correlation and not statistically significant among different sources of income generation. However, the results show that about 77% of sampled farmers sold cereals surplus. Moreover, cotton growers obtain income from multiple sources by selling sale of vegetable, horticultural commodities and cattle. Econometric results show that age of family head, family size, dependency ratio, land ownership, education level, cash crop income, off farm income, access to credit, high cost of agricultural inputs, infrastructure, price of agricultural commodities positively and significantly influenced the likelihood of farming families' participation in vegetable and horticultural production and marketing. The results also indicate that the expected sign of coefficient of extension services, education level and infrastructure negatively influenced farming family participation in vegetable and horticulture production and marketing.

On crops diversification strategies, findings show that farmers in Southern Mali engage in four diversification strategies such as cotton and maize; cotton maize and millet; cotton maize, millet and sorghum and cereals production. The share of cotton in the total cultivated land was 44%; 50%; 48% and 0% across the four systems respectively. The results also show that 74% of fields were located on sand and silt soils while the rest were spread across silt and clay, sand, clay and gravel soils at 1%; 4%; 9% and 12% respectively. Most of the results are reasonably consistent and in line with the previous studies. The MNL regression model revealed that the likelihood of diversification strategies is positively influenced by farmer and family characteristics and factors endowment. The estimates show that the ages of family head, education level, family size, oxen ownership, income per capita and crop pests significantly influenced smallholder farmers' participation in the four diversification strategies. The results also indicate that smallholder farmers with larger family size were more likely to diversify into three diversification strategies compared to farmers only engaging in cereals production. Similarly, farmers owning oxen were more likely to diversify into cotton and maize. cotton and two cereals and cotton and three cereals.

The stochastic frontier production function for cotton shows that the quantity of NPK applied per hectare was positive and the most important variable influencing farmer's efficiency. The mean level of technical efficient was 84% and ranged between ranged between 29% and 100%. This suggests that there is an opportunity for smallholder farmers to improve the output of cotton with the same set of inputs given. The distribution of technical efficiency scores across 126 cotton producers shows that 11.11% of farmers had technical efficiency scores that were less than 60%. Whereas 32.54% level of farmers had technical efficiency scores between 60 to 89% and the majority of farmers 56.35% of farmers had the most technical efficient scores above 90 %. The specific practices among farmers show that the frequency of insecticide applied and weeding determines also affected the level of cotton output per hectare. The specific variables used to determine the inefficiencies among cotton producers were the age of family head and family size. However, age of family head tends to be the most efficient. The variable family size had a negative influence on increasing technical efficiency in cotton farming.

The results of stochastic frontier production function of maize showed that the labour and the quantity of NPK per hectare positively influenced farmer's efficiency while the plot size under maize and the quantity of urea applied per hectare negatively influenced farmer's efficiency. The mean technical efficiency level was 58% which ranged between 0.65 to 100%. In other words, on average smallholder farmer's maize producers would have produced about 42% more output with the same set of inputs given if the farmers were to produce on the most technically efficiency frontier. About 40.60% of farmers were found to have a technical efficiency score at 40% levels. At 45.11% level farmers had a technical efficiency score ranked between 50 to 70% and 14.29% of farmers having technical efficiency above 70%. The technical inefficiency variables indicated that farmers who had access to agricultural extension services were more efficient. The variables low agricultural inputs applied per hectare and off-farm income negatively influenced technical efficiency in maize production.

The Cobb-Douglas stochastic frontier production function for millet shows that the variables labour and the quantity of urea applied per hectare were positive and significantly influenced farmer's technical efficiency whereas the quantity of NPK applied per hectare and land size under millet negatively influenced farmer's efficiency. The mean technical efficiency was 58% and ranged between 15 to 99%. In other worlds, farmers could achieve about 42 % of the potential maximum output from a given set of inputs with the current technology. The distribution of technical efficiency (TE) scores indicated that 42.86% of farmers had efficiency scores less than 40%, and 28.57% of farmers had technical efficiency scores between 50 and 70% and 28.58% of farmers had technical efficient scores above 80%. The variable the frequency of weeding among millet producers influenced positively the technical efficiency on millet output per hectare. The determinants of technical inefficiency were access to agricultural credit and education positively affect the technical efficiency. The variables access to agricultural extension services and off-farm income negatively influence technical efficiency for farmers who produce millet.

The results of stochastic frontier production function for sorghum showed that the variable labour was positive and significant while the fertilizer applied was negative and significantly influenced the technical efficiency of sorghum farmers. The estimated result of technical efficiency mean was 80% which ranged between 21 to 99% suggesting that opportunities still exist to increase the efficiency by improving the use of set of inputs given. The results indicate that 14.04% of farmers had technical efficient score below 50% and 22.81% of farmer's had technical efficiency from 50 up to 80%, and 63.16% of farmers had technical efficiency above 90%. The specific practice of sorghum farmers which influenced positively sorghum output was the quantity of urea per hectare while the quantity of NPK applied per hectare and frequency of weeding influence negatively influenced technical efficiency.

The study found out that the most important factor which explains the technical inefficiency was oxen ownership. The variables access to agricultural extension services and off-farm income had a negative influence in increasing technical efficiency.

The results of logit regression model showed that socio-economics factors and farmers specific practices affected the decision of practice of organic matter applied under allocated land size of cotton. The findings indicate that labour, education level affect the decision to adopt of organic matter production. The variables transhumance of (cattle) and the frequency of weeding influence significantly the practice of organic matter production. These practices reduce significantly the likelihood of practice with more practice of transhumance of cattle and frequency of weeding. Labour availability increases significantly the likelihood of practice of organic matter production. The MVP model was used to analyse the probability of practice of multiple agricultural technology at plots level observations. The results indicate that there are strong complementarities and substitutabilities between agricultural technologies. The results showed that agricultural technology is influenced by socioeconomic factors such as land size under maize, agricultural tools, land ownership, off-farm income, institutional factor (access to agricultural credit) and farmers practice (frequency of weeding). The bivariate regression model was used to understand the adoption of agricultural technology by millet and sorghum farmers in cotton growing zone of Mali. Findings suggest that socioeconomic characteristics such as age of family head, family size, education level, agricultural tools and plot size, institutional factors such as access to agricultural credit and access to agricultural extension services influenced the probability to adopt plough + sowing and inorganic matter application. The probability of practice of plough + sowing increased with family size while it decreased with age of family head and education level for both millet and sorghum farmers. The probability of practice of inorganic matter increased with education level, agricultural tools, access to agricultural extension services, plot size but decreased with family size, high price of agricultural inputs, oxen ownership and access to agricultural inputs in both cropping system millet and sorghum.

Agricultural input subsidies improve the livelihood of smallholder farmers operating in a closed economy. However, the five types of farming families differ in GM. The share of land allocated to cotton production in the crop rotation systems is more or less likely to impact on the GM of the five types of farming families. In the long-run, all types of farming families increase their GM after the decline at the beginning. As GM increase due to an increase in the size of land allocated to cotton, there may be a negative influence on cereals production, leading to food insecurity. Non-subsidy of agricultural inputs would lead a decrease in GM for the five types of farming families. Except for the GM of Type3 farming families that decrease across the years, the GM for the other four types of farming families are almost constant over the ten years. In other words, with or without subsidies, farmers grow cotton in order to maintain their access to agricultural inputs for both cotton and cereals production. In addition, access to agricultural inputs depends on farmer involvement in cotton production which is an important barrier to poverty alleviation in the rural areas. Overall, the decrease in land allocation to cotton production results in relatively improved GM for all types of farming families in the cotton growing zone. However, the GM increase in the long-run after a decrease at the beginning of the scenario. Agricultural input subsidy allows farmers to earn extra income from cotton selling after input cost deductions. In other words, cotton remains a survival crop although its income to farmers is still problematic. The agricultural input subsidy program constitutes the backbone of agricultural development in developing countries, especially in the cotton growing zone of Mali where liquidity constraint is a major factor that hinder the use of commercial inputs. It is well understood that cotton production in Southern Mali is the engine of agricultural growth in Mali. Hence, a decline in agricultural production in Southern Mali is synonymous with poor agricultural production and productivity in the country.

### 5.2. Recommendations

1. The findings of this study may assist policymakers and future researchers in designing measures for achieving the sustainable development goals. For instance, study recommends interventions such as the development and modernization of milk, meat and horticulture value chains in Southern Mali. There are several and alternative development interventions can be used to improve the livelihoods of the rural population. Based on multiple sources of

income, there is a need to consider vegetable and horticulture production as a business not as subsistence agriculture in Southern Mali. There is need to subsidize the agricultural inputs to enhance smallholder livelihood through agricultural productivity and participation in market outlet.

2. Based on findings, it is important for the government to encourage smallholder farmers to diversify their agricultural production system to achieve food self-sufficiency and enhance family income. In addition, having a cash crop and engaging in cereals production and livestock rearing contribute to the reduction of extreme poverty, malnutrition and food insecurity. Policy interventions should encourage and promote better access to agricultural inputs and improve options for diversification.

3. Technical efficiencies of stochastic frontier analysis of cotton, sorghum and (maize and millet) could be increased by 16%, 20% and 42% on average respectively through better use of available resources such as NPK, urea, labour, land size given the current set of inputs and technology. Inefficiency effects on technical efficiency can be reduced significantly by strengthening access to agricultural services, education level, providing access to greater agricultural inputs, oxen ownership, increasing the frequency of applying insecticide and advising farmers on frequency of weeding. From the findings several policy implications can be addressed to the government and decision makers in order to increase agricultural productivity in Southern-Mali. In agricultural technologies practice some variables are key component in practice of more complex agricultural technologies such as education level, land holding, institutional factors agricultural equipment among others. Thus, improving and strengthen those factors at smallholder farmer’s levels would lead to the increased agricultural productivity, reduced food insecurity, poverty reduction and malnutrition status. Additionally, policy makers should promote agricultural development and spread appropriate agricultural technologies in rural areas in order to achieve the sustainable development goal of reducing of poverty and hunger in least developing countries.

4. The government should maintain agricultural input subsidy program which would not only increase cotton productivity but also improve the livelihoods of smallholder farmers in cotton growing zone of Mali. The subsidy program should be inclusive and offer market-based solutions to agricultural input use. This should include broadening of the subsidy programs to cover non-cotton farming. This will not only be essential in increasing farmer access to the input market, but also critical to the improvement of cereals productivity. The policy

approach in this context should focus on the role of subsidy programs on the diverse or alternative sources of farm income.

### 5.3. Future research

1. The typology that was established in 1996 should be updated to capture the current situations by taking into accounts some relevant variables.
2. It should consider implementation of adequate and sustainable agricultural technologies in order to provide pathways for diversification of crop enterprises.
3. To understand smallholder farmer's agricultural technologies adoption, more research is demanded to measure and quantify the introduced agricultural technologies on crop and livestock integration systems in Southern-Mali.

## REFERENCES


Abate, T., Shiferaw, B., Menkir, A., Wegary, D., Kebede, Y., Tesfaye, K., … Keno, T. (2015). Factors that transformed maize productivity in Ethiopia. *Food Security*, *7*, 965–981. http://doi.org/10.1007/s12571-015-0488-z

Abdalla, S., Leonhäuser, I., Bauer, S. and Elamin, E. (2013). Factors influencing crop diversity in dry land sector of sudan. *Journal of Agricultural Research*, *2*(7), 88–97.

Abdul-rahaman, A. (2016). Stochastic frontier analysis (SFA) of technical efficiency, insights from smallholder cotton farmers in the Northern Region of Ghana. *Global Journal of Agricultural Economics, Extension and Rural Development*, *4*(1), 361–367.

Abdulai, A. and Crolerees, A. (2001). Determinants of Income Diversification among Rural Households in Southern Mali. *Food Policy*, *26*, 437–452. http://doi.org/10.1016/S0306-9192(01)00013-6

Abdullah, Rabbi, F., Ahamad, R., Ali, S., Ali, A., Ahmad, W. and Ilyas, A. (2017). Determinants of commercialization and its impact on the welfare of smallholder rice farmers by using Heckman's two-stage approach. *Journal of the Saudi Society of Agricultural Sciences*, (In PRESS). http://doi.org/10.1016/j.jssas.2017.06.001

Abimbola, O. A. and Oluwakemi, A. O. (2013). Livelihood diversification and welfare of rural households in Ondo State, Nigeria. *Journal of Development and Agrciultural Economics*, *5*(12), 482–489. http://doi.org/10.5897/JDAE2013.0497

Abro, A. A. (2012). Determinants of crop diversification towards high value crops in Pakistan. *International Journal of Business Management Economics Resources*, *3*(3), 536–545.

Abu, B. M., Issahaku, H. and Nkegbe, P. K. (2016). Farmgate versus market centre sales : a multi-crop approach. *Agricultural and Food Economics*, *4*, 1–17. http://doi.org/10.1186/s40100-016-0065-6

Adzawla, W. Fuseini, J. and Donkoh, S. (2013). Estimating Technical Efficiency of Cotton Production in Yendi Municipality, Northern Ghana. *Journall of Agriculture and Sustainability*, *4*(1), 115–140.

Ahmed, Adam, E., Kuhlmann, F., Mau, M., Elobeid, H. A. and Elamin, E. M. (2005). Analysis of factors affecting Sorghum production levels in the Gezira scheme and its implications on the Household food security (pp. 1–10). Stuttgart-Hohenheim.

Ahmed, M. H., Geleta, K. M., Tazeze, A., Mesfin, H. M. and Tilahun, E. A. (2017). Cropping systems diversification , improved seed , manure and inorganic fertilizer adoption by maize producers of eastern Ethiopia. *Journal of Economic Structures*, *6*, 1–16. http://doi.org/10.1186/s40008-017-0093-8

Ahmed, M. H., Lemma, Z. and Endrias, G. (2014). Technical efficiency of maize producing farmers in Arsi Negelle, Central Rift valley of Ethiopia: Stochastic frontier approach. *Agriculture &Forestry*, *60*(1), 157–167.

Ahmed, T., Bhandari, H., Gordoncillo, P. U., Quicoy, C. B. and Carnaje, G. P. (2015). Diversification of rural livelihoods in Bangladesh. *Journal of Agricultural Economics and Rural Development*, *2*(2), 32–38.

Aigner, D., Lovell, C. A. K. and Schmidt, P. (1977). Formultion and estimation of stochastic frontier production function models. *Journal of Econometrics*, *6*, 21–37.

Alabi, O. O., Lawal, A. F., Coker, A. A. and Awoyinka, Y. A. (2014). Probit model anlysis of smallholder's farmers decision to use agrochemical inputs in Gwagwalada and Kuje concils of Federal capital territory, Abuja, Nigeria. *International Journal of Food and Agricultural Economics*, *2*(1), 85–93.

Alary, V. and Dieye, P.N. (2006). Etude du Commerce Régional de bétail entre le Mali et l'Algérie. Field review STDF (Standard and Trade Development Facilities) 13. FAO/OIE, Rapport CIRAD, Montpellier, France, 31p.

Ali, A. and Erenstein, O. (2017). Climate Risk Management Assessing farmer use of climate change adaptation practices and impacts on food security and poverty in Pakistan. *Climate Risk Management*, *16*, 183–194. http://doi.org/10.1016/j.crm.2016.12.001

Alvarez-Lopez, C. J., Riveiro, J. A. and Marey, M. F. (2008). Typology , classification and characterization of farms for agricultural production planning, *6*(1), 125–136.

Amsalu, A. and Graaff, J. De. (2006). Determinants of adoption and continued use of stone terraces for soil and water conservation in an Ethiopian highland watershed. *Ecological Economics*, *1*, 294–302. http://doi.org/10.1016/j.ecolecon.2006.01.014

Aneani, F., Anchirinah, V., Owusu-Ansah, F. and Asamoah, M. (2011). An analysis of the extent and determinants of crop diversification by cocoa ( Theobroma cacao ) farmers in Ghana. *African Journal of Agricultural Research*, *6*, 4277–4287. http://doi.org/10.5897/AJAR10.1083

Archibald, B., Agyeman, S., Asuming-brempong, S. and Onumah, E. E. (2014). Determinants of Income Diversification of Farm Households in the Western Region of Ghana. *Quarterly Journal of International Agriculture*, *53*(1), 55–72.

Asfaw, A., Simane, B., Hassen, A. and Bantider, A. (2017). Determinants of non-farm livelihood diversification : evidence from rainfed-dependent smallholder farmers in northcentral Ethiopia ( Woleka sub-basin ). *Development Studies Research*, *4*, 22–36. http://doi.org/10.1080/21665095.2017.1413411

Asfaw, S., Pallante, G. and Palma, A. (2018). Diversification Strategies and Adaptation Deficit : Evidence from Rural Communities in Niger. *World Development*, *101*, 219–234. http://doi.org/10.1016/j.worlddev.2017.09.004

Asfaw, S., Shiferaw, B., Simtowe, F. and Lipper, L. (2012). Impact of modern agricultural technologies on smallholder welfare : Evidence from Tanzania and Ethiopia. *Food Policy*, *37*, 283–295.

Asmah, E. E. (2011). Rural livelihood diversification and agricultural household welfare in Ghana. *Journal of Development and Agricultural Economics*, *3*(7), 325–334. http://doi.org/10.5539/jsd.v6n6p121

Audu, V. I. and Aye, G. C. (2014). The effects of improved maize technology on household welfare in Buruku, Benue State, Nigeria. *Cogent Economics & Finance*, *2*, 1–10. http://doi.org/10.1080/23322039.2014.960592

Ayadi, H., Bars, M. Le, Grusse, P. Le, Mandart, E., Fabre, J. and Bouaziz, A. (2013). SimPhy: a simulation game to lessen the impact of phytosanitaries on health and the environment—the case of Merja Zerga in Morocco. *Envrionmental Scince and Pollution Research*, *13*, 1–10. http://doi.org/10.1007/s11356-013-2244-2

Ba, A., Lesnoff, M., Poccard, R. C. and Moulin, C.-H. (2011). Demographic dynamics and off-take of cattle herds in southern Mali. *Tropical Animal Health and Production*, *43*(6), 1101–1109. http://doi.org/10.1007/s11250-011-9808-2

Babatunde, R. O., Omotesho, O. A. and Olorunsanya, E. O. (2008). Determinants of vulnerability to food insecurity : A gender- based analysis of farming households in Nigeria. *Indian Journal of Agricultural Economics*, *63*(1), 116–125.

Babulo, B., Muys, B., Nega, F., Tollens, E. F., Nyssen, J., Deckers, J. and Mathijs, E. (2008). Household livelihood strategies and forest dependence in the Highlands of Tigray. *Agricultural Systems*, *98*, 147–155. http://doi.org/10.1016/j.agsy.2008.06.001

Badiane, O., Ghura, D., Goreux, L. and Paul, M. (2002). *Cotton Sector Strategies in West and Central Africa. p21*. (No. Working paper WP/02/173).

Baffes, J. (2007). Distortions to Cotton Sector Incentives in West and Central Africa. p21. (p. 12).

Bakhsh, K., Maqsood, A., Hassan, S. and Kamran, M. A. (2014). The economic role of livestock assets in cotton productivity in Punjab, Pakistan. *Pakistan Journal of Agriculture Science*, *51*(4), 1091–1094.

Bamine, A., Fabiyi, Y. L. and Manyong, V. M. (2002). Adoption pattern of fertiliser technology among farmers in the ecological zones of south-western Nigeria: a Tobit analysis. *Australian Journal of Agricultural Research*, *53,* 901–910.

Baquedano, F. G., Sanders, J. H. and Vitale, J. (2010). Increasing incomes of Malian cotton farmers: Is elimination of US subsidies the only solution? *Agricultural Systems*, *103*(7), 418–432. http://doi.org/10.1016/j.agsy.2010.03.013

Barrett, C. B. (2001). Nonfarm income diversification and household livelihood strategies in rural Africa : Concepts, Dynamics and and policy implications. http://doi.org/10.1016/S0306-9192(01)00014-8

Barrett, C. B., Bezuneh, M., Clay, D. C. and Reardon, T. (2000). Heterogeneous constraints , incentives and income diversification strategies in rural Africa. *Quarterly Journal of International Agriculture*, pp 44. http://doi.org/org/10.2139/ssrn.258371

Barrett, J. C. (1991). The economic role of cattle in communal farming systems in Zimbabw This paper is concerned with understanding cattle production in Zimbabwe ' s.

Basantaray, A. K. and Nancharaiah, G. (2017). Relationship between Crop Diversification and Farm. *Agricultural Economics Research Review*, *30*, 45–58. http://doi.org/10.5958/0974-0279.2017.00021.0

Battese, G. E. (1992). Frontier production functions and technical efficiency : a survey of empirical applications in agricultural economics. *Agricultural Economics*, *7*, 185–208.

Battese, G. E. and Coelli, T. J. (1988). Prediction of firm-level technical efficiencies with a generalized frontier production function and panel data. *Journal of Econometrics*, *38*, 387–399.

Battese, G. E. and Coelli, T. J. (1995). A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data. *Empirical Economics*, *20*, 325–332.

Bekele, W. and Drake, L. (2003). Soil and water conservation decision behavior of subsistence farmers in the Eastern Highlands of Ethiopia : a case study of the Hunde-Lafto area. *Ecological Economics*, *46*, 437–451. http://doi.org/10.1016/S0921-8009(03)00166-6

Belay, A., Recha, J. W., Woldeamanuel, T. and Morton, J. F. (2017). Smallholder farmers' adaptation to climate change and determinants of their adaptation decisions in the Central Rift Valley of Ethiopia. *Agriculture & Food Security*, *6*, 1–13. http://doi.org/10.1186/s40066-017-0100-1

Bell, L. W., Moore, A. D. and Kirkegaard, J. A. (2014). Evolution in crop – livestock integration system that improve farm productivity and environmental performance in Australia. *European Journal of Agronomy*, *57*,10–20. http://doi.org/10.1016/j.eja.2013.04.007

Bempomaa, B. and Acquah, H. (2014). Technical Efficiency Analysis of Maize Production : Evidence from Ghana. *Applied Studies in Agribusiness and Commerce*, *8*(2), 73–79.

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

Berthé A. L., Blockland A., Bouaré S., Diallo B., Diarra M. M. and Geerling, C. (199). Etat des ressources naturelles et potentialités de développement, Profil d'environnement Mali-Sud, KIT, Amsterdam (NL).79p

Bezu, S., Kassie, G. T. and Lafayette, W. (2014). Impact of Improved Maize Adoption on Welfare of Farm Households in Malawi : A Panel Data Analysis. *Wold Development, 59*, 120–131. http://doi.org/10.1016/j.worlddev.2014.01.023

Bigsten, A. and Tengstam, S. (2011). Smallholder Diversification and Income Growth in Zambia. *Jouranl of African Economics*, *20*, 781–822. http://doi.org/10.1093/jae/ejr017

Binam, N. J., Tonye, J., Nyambi, G. and Akoa, M. (2008). Factors affecting the technical efficiency among smallholder farmers in the slash and burn agriculture zone of Cameroon. *Food Policy*, *29*(2004), 531–545. http://doi.org/10.1016/j.foodpol.2004.07.013

Binswanger-mkhize, H. P. and Savastano, S. (2017). Agricultural intensification : The status in six African countries. *Food Policy, 67,* 26–40. http://doi.org/10.1016/j.foodpol.2016.09.021

Blanchard, M. (2010). Gestion de la fertilite des sols et role du troupeau dans les systemes coton-cereales-elevage au Mali-Sud. Savoirs techniques locaux et pratiques d' integration agriculture elevage. PhD Thesis, Universite Paris-Est, Creteil, Val De Marne. France, 261pp+ Annexe

Bozoglu, M. and Ceyhan, V. (2007). Measuring the technical efficiency and exploring the inefficiency determinants of vegetable farms in Samsun province, Turkey. *Agricultural Systems*, *94,* 649–656. http://doi.org/10.1016/j.agsy.2007.01.007

Bradley, R. (2010). Integrated Farming Systems. The past or the future? Nuffield Australia.

Chang, H. and Wen, F. (2011). Off-farm work , technical efficiency , and rice production risk in Taiwan. *Agricultual Economics*, *42*, 269–278. http://doi.org/10.1111/j.1574-0862.2010.00513.x

Chepng'etich, E., Bett, E. K., Nyamwaro, S. O. and Kizito, K. (2014). Analysis of Technical Efficiency of Sorghum Production in Lower Eastern Kenya : A Data Envelopment Analysis ( DEA ) approach . *Journal of Economics and Sustainable Development*, *5*(4), 58–65.

Chepng'etich, E., Nyamwaro, S. O., Bett, E. K. and Kizito, K. (2015). Factors that influence technical efficiency of sorghum production : A case of small holder sorghum producers in lower Eastern Kenya. *Advances in Agriculture*, 1–11.

Chiona, S., Kalinda, T. and Tembo, G. (2014). Stochastic frontier analysis of the technical efficiency of smallholder maize farmers in Central Province, Zambia. *Journal of Agricultural Science*, *6*(10), 108–118. http://doi.org/10.5539/jas.v6n10p108

Chirwa,  phraim W. (2005). Adoption of fertiliser and hybrid seeds by smallholder maize farmers in Adoption of fertiliser and hybrid seeds by smallholder maize farmers in southern Malawi. *Development Southern Africa*, *22*, 1–12. http://doi.org/10.1080/03768350500044065

Company Malian Development of Textile. (2005). Monitoring –Evaluation Data Base

Company Malian Development of Textile. (2013). Monitoring –Evaluation Data Base.

Coelli, T. J., Rao, P. D. S., O'Donnell, C. J. and  Battese, G. E. (2005). An introduction to efficiency and productivity analysis. Australia.

Coulibaly, D. (2008). Changements socio-techniques dans les systèmes de production laitière et commercialisation en zone peri-urbaine de Sikasso, Mali. PhD Thesis, Agro Paris Tech. France, 285p + Annexe

Cunguara, B. and Darnhofer, I. (2011). Assessing the impact of improved agricultural technologies on household income in rural Mozambique. *Food Policy*, *36*, 378–390. http://doi.org/10.1016/j.foodpol.2011.03.002

Daloglu, I., Iverson, J., Riolo, R. L. and Scavia, D. (2014). Development of a farmer typology of agricultural conservation behavior in the American Corn Belt. *Agricultural Systems*, 1–10. http://doi.org/10.1016/j.agsy.2014.05.007

Deininger, K. and Byerlee, D. (2012). The Rise of Large Farms in Land Abundant Countries : Do They Have a Future ? *World Development*, *40*(4), 701–714.

http://doi.org/10.1016/j.worlddev.2011.04.030

Deininger, K., Savastano, S. and Xia, F. (2017). Smallholders ' land access in Sub-Saharan Africa : A new landscape ? *Food Policy*, *67*, 78–92. http://doi.org/10.1016/j.foodpol.2016.09.012

Delarue, J., Mesple-somps, S., Naudet, J.-D. and Robilliard, A. (2009). Le paradoxe de Sikasso : coton et pauvreté au Mali (Document de travail DT/2009-09 No. Document de travail DT/2009-09). Paris.

Dembele, B. (2008). Utilisation des pailles et des fanes dans huit villages de la zone cotonnière du Mali dans les systèmes agriculture- élevage. Msc, Thesis, SupAgro, Montpellier, France. 49p

Demie, A. and Zeray, N. (2015). Nonfarm Income Diversification and Inequality in Eastern Ethiopia : Evidence from Gini Decomposition Analysis. *Journal of Poverty, Investment and Development*, *18*, 7–14.

Demissie, A. and Legesse, B. (2013). Determinants of income diversification among rural households : The case of smallholder farmers in Fedis district, Eastern hararghe zone, Ethiopia. *Journal of Development and Agricultural Economics*, *5*, 120–128. http://doi.org/10.5897/JDAE12.104

Deressa, Tadesse, T., Hassan, R. M., Ringler, C., Alemu, T. and Yusuf, M. (2009). Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global Environmental Change*, 1–9. http://doi.org/10.1016/j.gloenvcha.2009.01.002

Descheemaeker, K., Amede, T. and Haileslassie, A. (2010). Improving water productivity in mixed crop – livestock farming systems of Sub-Saharan Africa. *Agricultural Water Management*, *97*, 579–586. http://doi.org/10.1016/j.agwat.2009.11.012

Deveze, J. C. and Des Fontaines, D. H. (2007). Le devenir des agricultures cotonnières : Cas du Cas du Mali, Agence Française Développement, Paris. pp 20

Dey, S. (2018). The role of employment diversification in reducing vulnerability to poverty among marginal and small-holder agricultural households in India. *The Journal of Applied Economic Research*, *1*, 88–112. http://doi.org/10.1177/0973801017740661

Diarisso, T., Corbeels, M., Andiieu, N., Djamen, P. and Tittonell, P. (2015). Biomass transfers and nutrient budgets of the agro-pastoral systems in a village territory in south-western Burkina Faso. *Nutrient Cycling in Agroecosystems*, *101*(3), 295–315. http://doi.org/10.1007/s10705-015-9679-4

Dillon, B. and Barrett, C. B. (2017). Agricultural factor markets in Sub-Saharan Africa : An updated view with formal tests for market failure. *Food Policy*, *67*, 64–77. http://doi.org/10.1016/j.foodpol.2016.09.015

Djouara, H., Belieres, J.-F. and Kebe, D. (2006). Les exploitations agricoles familiales de la zone cotonniere du Mali face a la baisse des prix du coton- graine. *Cahiers Agricultures*, *15*, 64–71.

Dlamini, S. I., Masuku, M. B. and Rugambisa, J. I. (2012). Technical efficiency of maize production in Swaziland : A stochastic frontier approach. *African Journal of Agricultural Research*, *7*(42), 5628–5636. http://doi.org/10.5897/AJAR12.1204

Dossa, L. H., Abdulkadir, A., Amadou, H., Sangare, S. and 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*, *12*, 197–206. http://doi.org/10.1016/j.landurbplan.2011.04.005

Douxchamps, S., Wijk, M. T. Van, Silvestri, S., Moussa, A. S., Kristjanson, P., Ouedraogo, M., … Zougmore, R. (2016). Linking agricultural adaptation strategies , food security and vulnerability : evidence from West Africa. *Regional Environmental Change*, 1305–1317. http://doi.org/10.1007/s10113-015-0838-6

DNPIA, 2010. Rapport annuel. Ministère de l'élevage et de la pêche, Bamako, Mali, 113p.

Ellis, F. (2000). The determinants of rural livelihood diversification in developing countries. *Journal of Agricultural Economics*, *51*(2), 289–302.

Ellis, F. and Freeman, H. A. (2004). Rural livelihoods and poverty reduction in four African countries strategies. *Journal of Development Studies*, *40*, 1–30. http://doi.org/10.1080/00220380410001673175

Esham, M. (2014). Technical efficiency and determinants of maize production by smallholder farmers in the Moneragala District of Sri Lanka. *Mediterranen Journal of Social Sciences*, *5*, 416–422. http://doi.org/10.5901/mjss.2014.v5n27p416

Fabusoro, E., Omotayo, A. M., Apantaku, S. O. and Okuneye, P. A. (2010). Forms and Determinants of Rural Livelihoods Diversification in Ogun State, Nigeria. *Journal of Sustainable Agriculture*, *34*, 417–438. http://doi.org/10.1080/10440041003680296

Falconnier, G. N., Descheemaeker, K., Mourik, T. A. Van, Sanogo, O. M. and Giller, K. E. (2015). Understanding farm trajectories and development pathways : Two decades of change in southern Mali. *Agricultural Systems*, *139*, 210–222. http://doi.org/10.1016/j.agsy.2015.07.005

FAO. (2014). The State of Food and Agriculture.

FAO. (2015). Regional overview of food insecurity Africa. African food seurityprospects, brighter than ever. Accra.

Faruque, G., Ullah, W., Deb, U., Ahmed, C. S., Mandal, N., Paul, B. and Khan, T. F. (2014). Agricultural Production Typology in Bangladesh. Conference of the Asian Society of Agricultural Economists *(ASAE).p24* (Vol. 24).

Fedoroff, N. V. (2015). Food in a future of 10 billion. *Agriculture & Food Security*, *4*(1), 11. http://doi.org/10.1186/s40066-015-0031-7

Forsund, F. R., Lovell Knox, C. A. and Schmidt, P. (1980). A survey of frontier production functios and of their relationship to efficiency measurement. *Journal of Econometrics*, *13*, 5–25.

Fosu-mensah, B. Y., Vlek, P. L. G. and Maccarthy, D. S. (2012). Farmers' perception and adaptation to climate change : a case study of Sekyedumase district in Ghana. *Environmental Development Sustainable*, *14*, 495–505. http://doi.org/10.1007/s10668-012-9339-7

Franzluebbers, A. J. (2007). Integrated Crop–Livestock Systems in the Southeastern USA. *Agronomy Journal*, *372*, 361–372. http://doi.org/10.2134/agronj2006.0076

Gautam, Y. and Andersen, P. (2016). Rural livelihood diversification and household well-being : Insights from Humla , Nepal. *Journal of Rural Studies*, *44*, 239–249. http://doi.org/10.1016/j.jrurstud.2016.02.001

Ghimire, R., Wen-chi, H. U. and Hrestha, R. B. S. (2014). Factors affecting adoption of improved rice varieties among rural farm households in Central Nepal. *Rice Science, 22*(1), 35–43. http://doi.org/10.1016/S1672-6308(14)60278-X

Gigou, J., Giraudy, F., Doucoure, C. O. T., Healy, S., Traore, K. and Guindo, O. (2004). L'age des champs : un indicateur du passage de la culture itinérante à la culture permanente dans le bassin cotonnier du Mali. *Cahiers Agricultures*, *467–472*, 467–472.

Giller, K. E., Tittonell, P., Rufino, M. C., Wijk, M. T. Van, Zingore, S., Mapfumo, P., … Vanlauwe, B. (2010). Communicating complexity : Integrated assessment of trade-offs concerning soil fertility management within African farming systems to support innovation and development. *Agricultural Systems*, *1–13*, 13. http://doi.org/10.1016/j.agsy.2010.07.002

Girei, A., Dire, B., Iliya, M. and Salihu, M. (2013). Stochastic frontier production function on the resource use efficiency of Fadama II crop farmers in Adamawa State, NIGERIA.

*European Journal of Agricultural and Forestry Research*, *1*, 1–15.

Gondwe, T. M., Alamu, E. O., Musonda, M. and Geresomo, N. (2017). The relationship between training farmers in agronomic practices and diet diversification : a case study from an intervention under the Scaling Up Nutrition programme in Zambia. *Agriculture & Food Security*, *6*, 1–7.

Goshu, D., Kassa, B. and Ketema, M. (2012). Does crop diversification enhance household food security ? evidence from Rural Ethiopia. *Advances in Agriculture, Sciences and Engineering Research*, *2*, 503–515.

Graeub, B. E., Chappell, M. J. and Wittman, H. (2016). The state of family farms in the world. *World Development*, *87,* 1–15. http://doi.org/10.1016/j.worlddev.2015.05.012

Greene, W. H. (2002). *Econometric analysis Seventh Edition*. New York Univrsoty. pp 1056

Grusse, P. Le, Hatem, B., Le Bars, M., Carmona, G. and Attonaty, J. M. (2006). Participative modelling to help collective decision-making in water allocation and nitrogen pollution : application to the case of the Aveyron-Lère Basin. *International Journal of Agrircultural Resources, Governace and Ecology*, *5*, 247–271.

Haggblade, S., Hazell, P. B. R. and Reardon, T. (2009). Tranforming the rural nonfar economy: Opportunities and threats in the developing World.

Haggblade, S., Hazell, P. and Brown, J. (1989). Farm-nonfarm linkages in rural Sub-Saharan Africa. http://doi.org/10.1016/0305-750X(89)90232-5

Haggblade, S., Hazell, P. and Thomas, R. (2010). Rural non-farm income in developing countries The rural non-farm economy : Prospects for growth and poverty reduction. *World Development*, *38*, 1429–1441. http://doi.org/10.1016/j.worlddev.2009.06.008

Haileslassie, A., Peden, D., Gebreselassie, S., Amede, T. and Descheemaeker, K. (2009). Livestock water productivity in mixed crop – livestock farming systems of the Blue Nile basin : Assessing variability and prospects for improvement. *Agricultural Systems*, 1–9. http://doi.org/10.1016/j.agsy.2009.06.006

Hassan, R. and Nhemachena, C. (2008). Determinants of African farmers' strategies for adapting to climate change: Multinomial choice analysis. *African Journal of Agricultural and Resource Economics*, *2*(1), 83–104.

Headey, D. D. and Jayne, T. S. (2014). Adaptation to land constraints : Is Africa different ? *Food Policy*, *48*, 18–33. http://doi.org/10.1016/j.foodpol.2014.05.005

Herrero, M., Thornton, P. K., Gerber, P., Herrero, M., Thornton, P. K., Gerber, P. and Reid, R. S. (2009). Livestock, Livelihoods and the environment : Understanding the trade-offs.

*Environmental Sustainability*, *1*, 111–120. http://doi.org/10.1016/j.cosust.2009.10.003

IFAD. (2010). *Integrated crop-livestock farming systems*.

IFPRI. (2004). Ending hunder in Africa: Prospects for the smallfFarmer. *Policy Brief,* International Food Policy Research Institute, Washington DC.

Iheke, O. R. and Agodike, W. C. (2016). Analysis of factors influencing the adoption of climate change mitigating measures by smallgolder farmers n Imo State, Nigeria. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development*, *16*(1), 213–220.

INSTAT (Institut National de la Statistique) (2009). Enquête par Grappe à Indicateurs Multiples et de Dépenses des Ménages (MICS/ELIM). Résultats préliminaires du volet ELIM. Bamako Mai 2011, 114p. *http://www.mali-apd.org/IMG/file/pdf/ACTUALITE/ Rapport_ELIM_draft_06_06_11.pdf*

Jagwe, J., Machethe, C. and Ouma, E. (2010). Transaction costs and smallholder farmers' participation in banana markets in the Great Lakes Region of Burundi, Rwanda and the Democratic Republic of Congo. *African Journal of Agricultural and Resources Economics*, *6*(1), 302–3017.

Jansen, H. G. P., Rodriguez, A., Damon, A., Pender, J., Chenier, J. and Schipper, R. (2006). Determinants of income-earning strategies and adoption of conservation practices in hillside communities in rural Honduras. *Agriculutral Systems*, *88*, 92–110. http://doi.org/10.1016/j.agsy.2005.06.005

Jari, B. and Fraser, G. C. (2009). An analysis of institutional and technical factors influencing agricultural marketing amongst smallholder farmers in the Kat River Valley , Eastern Cape Province, South Africa. *African Journal of Agricultural Research*, *4*, 1129–1137.

Jones, P. G. and Thornton, P. K. (2008). Croppers to livestock keepers : livelihood transitions to 2050 in Africa due to climate change. *Environmental Science & Policy*. http://doi.org/10.1016/j.envsci.2008.08.006

Joshi, P., Gulati, A., Birthal, P. S. and Tewari, L. (2003). Agriculture diversification in South Asia : patterns , determinants and policy implications (No. No. 57). Washington, D.C.IFPRI MSSD. http://doi.org/10.2307/4415148

Kaminski, J. (2008). Cotton-cereal Systems in West and Central Africa : Opportunities and constraints for revenue-raising diversification FAO Working Paper under the AAACP Project.

Kante, S. (2001). Gestion de la fertilité des sols par classe d'exploitation au Mali-Sud. PhD

Thesis, Wageningen University. Wageningen Universite.

Kanyua, M. J., Ithinji, G. K., Muluvi, A. S., Gido, O. E. and Waluse, S. K. (2013). Factors influencing diversification and intensification of horticultural production by smallholder tea farmers in Gatanga District , Kenya. *Current Research Journal of Social Sciences*, *5*(4), 103–111.

Karimov, A. A. (2014). Factors affecting efficiency of cotton producers in rural Khorezm , Uzbekistan : Re-examining the role of knowledge indicators in technical efficiency improvement. *Agricultural and Food Economics*,1–16.

Kasem, S. and Thapa, G. B. (2011). Land Use Policy Crop diversification in Thailand : Status , determinants , and effects on income and use of inputs. *Land Use Policy*, *28*(3), 618–628. http://doi.org/10.1016/j.landusepol.2010.12.001

Kassie, G. W., Kim, S. and Fellizarjr, F. P. (2017). Determinant factors of livelihood diversification : Evidence from Ethiopia. *Cogent Social Sciences*, *26*, 1–16. http://doi.org/10.1080/23311886.2017.1369490

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F. and Mekuria, M. (2012). Adoption of interrelated sustainable agricultural practices in smallholder systems : Evidence from rural Tanzania. *Technological Forecasting & Social Change*, *80*(3), 525–540. http://doi.org/10.1016/j.techfore.2012.08.007

Kassie, M., NDiritu, S. W. and Stage, J. (2014). What determines gender inequality in household food security in Kenya? Application of exogenous switching treatment regression. *Word Developement*, *56*,, 153–171.

Kassie, M., Shiferaw, B. and Muricho, G. (2011). Agricultural Technology , Crop Income , and Poverty Alleviation in Uganda. *World Development*, *39*(10), 1784–1795. http://doi.org/10.1016/j.worlddev.2011.04.023

Kassie, M., Teklewold, H. and Jaleta, M. (2015). Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa. *Land Use Policy*, *42*, 400–411.

Kassie, M., Teklewold, H., Jaleta, M., Marenya, P. and Erenstein, O. (2014). Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa. *Land Use Policy*, *42*, 400–411.

Kea, S., Li, H. and Pich, L. (2016). Technical Efficiency and Its Determinants of rice production in Cambodia. *MDPI*, *Economies*, *4*, 1–17. http://doi.org/10.3390/economies4040022

Khan, W., Tabassum, S. and Ansari, S. A. (2017). Can Diversification of Livelihood Sources Increase Income of Farm Households ?. A Case Study in Uttar Pradesh. *Agricultural Economics Research Review*, *30*, 27–34. http://doi.org/10.5958/0974-0279.2017.00019.2

Khatiwada, S. P., Deng, W., Paudel, B. and Khatiwada, J. R. (2017). Household Livelihood Strategies and Implication for Poverty Reduction in Rural Areas of Central Nepal. *Sustianability, MDPI*, *9*, 1–20. http://doi.org/10.3390/su9040612

Khatun, D. and Roy, B. C. (2012). Rural Livelihood Diversification in West Bengal : Determinants. *Agricultural Economics Research Review*, *25*(1), 115–124.

Khonje, M., Manda, J., Alene, A. D. and Kassie, M. (2015). Analysis of Adoption and Impacts of Improved Maize Varieties in Eastern Zambia. *WORLD DEVELOPMENT*, *66*, 695–706. http://doi.org/10.1016/j.worlddev.2014.09.008

Koutou, M., Sangaré, M., Havard, M., Toillier, A., Sanogo, L., Thombiano, T. and Vodouhe, D. S. (2015). Sources de revenus et besoins d ' accompagnement des exploitations agricoles familiales en zone cotonnière ouest du Burkina Faso. *Biotechnol. Agron. Soc. Environ.*, *42–56*(1), 42–56.

Kuboja, N. M., Isinika, A. C. and Kilima, F. T. M. (2017). Determinants of economic efficiency among small- scale beekeepers in Tabora and Katavi regions , Tanzania : a stochastic profit frontier approach. *Developement Studies Research*, *1*(4), 1–8. http://doi.org/10.1080/21665095.2017.1355738

Kuivanen, K. S., Alvarez, S., Michalscheck, M., Descheemaeker, K. and Groot, J. C. J. (2016). Characterising the diversity of smallholder farming systems and their constraints and opportunities for innovation: A case study from the Northern Region, Ghana. *NJAS - Wageningen Journal of Life Sciences*. http://doi.org/10.1016/j.njas.2016.04.003

Langyintuo, A. S. and Mungoma, C. (2008). The effect of household wealth on the adoption of improved maize varieties in Zambia. *Food Policy*, *33*(6), 550–559. http://doi.org/10.1016/j.foodpol.2008.04.002

Lanjouw, J. O. and Lanjouw, P. (2001). The rural non-farm sector : issues and evidence from developing countries. *Agircultural Economics*, *26*, 1–23.

Lay, J., Mahmoud, T. O. and M'Mukaria, G. M. (2008). Few opportunities , much desperation : The dichotomy of non-agricultural activities and inequality in Western Kenya. *World Development*, *36*(12), 2713–2732. http://doi.org/10.1016/j.worlddev.2007.12.003

Lay, J., Narloch, U. and Mahmoud, T. O. (2009). Shocks, Structural Change, and the Patterns of Income Diversification in Burkina Faso . *African Development Bank*, 36–58.

Le Bars, M., Grusse, P. Le and Albouchi, L. (2014). AquaFej : a simulation game for planning water management – an experiment in central Tunisia. *International Journal of Sustainable Development*, *17*(3), 242–260.

Lenné, J. M. and Thomas, D. (2006). Integrating crop – livestock research and development in Sub-Saharan Africa Option, imperative or impossible ? *Agriculture*, *35*(3), 167–175.

Longpichai, O. (2013). Determinants of Adoption of Crop Diversification by Smallholder Rubber Producers in Southern Thailand : Implications on Natural Resource Conservation. *Kasetsart Journal of Social Science*, *382*, 370–382.

Lowder, S. K., Skoet, J. and Raney, T. (2016). The Number, Size, and Distribution of Farms , Smallholder Farms, and Family Farms Worldwide. *World Development*, *87*, 16–29. http://doi.org/10.1016/j.worlddev.2015.10.041

Maertens, M., Minten, B. and Swinnen, J. (2012). Modern food supply chains and development : Evidence from horticulture export sectors in Sub-Saharan Africa. *Development Policy Review*, *30*(4), 473–497.

Mahgoub, B. O., Elrasheed, M. M. M. and Abdelaziz, H. H. (2017). Analyzing the Technical Efficiency of Cotton Production in the Gezira Scheme, Sudan. *Asian Journal of Agricultural Extension, Economics & Sociology*, *21*(2), 1–7. http://doi.org/10.9734/AJAEES/2017/33878

Makate, C., Wang, R., Makate, M. and Mango, N. (2016). Crop diversification and livelihoods of smallholder farmers in Zimbabwe : adaptive management for environmental change. *SpringerPlus*, 1–18. http://doi.org/10.1186/s40064-016-2802-4

Makel, M. A. and Usami, K. (2009). Determinants of Non-farm Income Diversification in Developed Villages of Bangladesh. *American Journal of Economics and Business Administration*, *1*(2), 141–149.

Mango, N., Makate, C., Hanyani-mlambo, B., Siziba, S. and Lundy, M. (2015). A stochastic frontier analysis of technical efficiency in smallholder maize production in Zimbabwe : The post-fast-track land reform outlook. *Cogent Economics & Finance*, *6*(1), 1–14. http://doi.org/10.1080/23322039.2015.1117189

Marandure, T., Mapiye, C., Makombe, G., Strydom, P., Muchenje, V. and Dzama, K. (2016). Determinants and opportunities for commercial marketing of beef cattle raised on communally owned natural pastures in South Africa. *African Journal of Range*

*&Forage Science*, *33*(3), 199–209. http://doi.org/10.2989/10220119.2016.1235617

Mariano, J. M., Villano, R. and Fleming, E. (2012). Factors influencing farmers ' adoption of modern rice technologies and good management practices in the Philippines. *Agricultural Systems*, *110*, 41–53. http://doi.org/10.1016/j.agsy.2012.03.010

Martin, S. M. and Lorenzen, K. A. I. (2016). Livelihood Diversification in Rural Laos. *World Development*, *xx*, 1–13. http://doi.org/10.1016/j.worlddev.2016.01.018

Mastromarco, C. (2008). *Stochastic frontier models*. pp49

Mbata, J. N. (2001). Determinants of animal traction adoption in traditional agriculture : an application of the multivariate probit procedure to the case of Lesotho. *Development Southern Africa*, *18*, 309–325. http://doi.org/10.1080/0376835012006998

Mbetid-bessane, E., Havard, M., Nana, P. D., Djonnewa, A., Djondang, K. and Leroy, J. (2003). Typologies des exploitations agricoles dans les savanes d ' Afrique centrale Un regard sur les méthodes utilisées et leur utilité pour la recherche et le développement, 27–31.

Medina, G., Almeida, C., Novaes, E., Godar, J. and Pokorny, B. (2015). Development conditions for family farming : Lessons from Brazil, *74*, 386–396. http://doi.org/10.1016/j.worlddev.2015.05.023

Meert, H., Huylenbroeck, G. Van, Vernimmen, T., Bourgeois, M. and Hecke, E. Van. (2005). Farm household survival strategies and diversification on marginal farms. *Journal of Rural Studies*, *21*, 81–97. http://doi.org/10.1016/j.jrurstud.2004.08.007

Meraner, M., Heijman, W., Kuhlman, T. and Finger, R. (2015). Determinants of farm diversification in the Netherlands. *Land Use Policy*, *42*, 767–780. http://doi.org/10.1016/j.landusepol.2014.10.013

Mohamed, I. E. ., Ahmed, A. E. and Siddig, K. (2008). Technical efficiency of producing sorghum in Kordofan state: A case study of Habila mechanized rain-fed sectot. *Bangladesh Journal of Agricultural Sciences*, *35*(1), 17–22.

Moraes, de A., Carvalho, P. C. de F., Lustosa, S. C., Lang, R. C. and Deiss, L. (2014). Research on Integrated Crop-Livestock Systems in Brazil. *Resista Ciencia Agronomica*, *5*, 1024–1031.

Morris, W., Henley, A. and Dowell, D. (2017). Farm diversi fi cation , entrepreneurship and technology adoption : Analysis of upland farmers in Wales. *Journal of Rural Studies*, *53*, 132–143. http://doi.org/10.1016/j.jrurstud.2017.05.014

Murrell, E. G. (2017). Can agricultural practices that mitigate or improve crop resilience to climate change also manage crop pests? *Current Opinion in Insect Science*. http://doi.org/10.1016/j.cois.2017.07.008

Naim, A. M. El, Naim, A. M. El, Elobeid, H. A. and Ahmed, A. E. (2017). Factors affecting technical efficiency of sorghum production in New Halfa Agricultural production corporation, Sudan. *Academic Journal of Life Sciences*, *3*(May), 1–5.

Nations, U. (2017). *World population prospects*.

Neba, C., Ngassam, S. and Nzomo, J. (2010). The determinants of the technical efficiency of cotton farmers in Northern Cameroon. *Munich Personal RePEc Archive*, (24814).

Ngambeki, D. . S. ., Deuson, R. R. and Preckel, P.V. (2010). *I*ntegrating livestock into farming systems in Nothern Cameroon.

Nguyen, H. Q. (2017). Analyzing the economies of crop diversi fication in rural Vietnam using an input distance function. *Agricultural Systems*, *153*, 148–156. http://doi.org/10.1016/j.agsy.2017.01.024

Nigussie, Z., Tsunekawa, A., Haregeweyn, N. and Adgo, E. (2017). Land Use Policy Factors influencing small-scale farmers' adoption of sustainable land management technologies in north-western Ethiopia, *67*, 57–64. http://doi.org/10.1016/j.landusepol.2017.05.024

Njeru, M. E. (2013). Crop diversification : A potential strategy to mitigate food insecurity by smallholders in sub-Saharan Africa. *Journal of Agriculture, Food Systems and Comminity Development*, *3*(4), 63–69.

Nkamleu, G. B. and Adesina, A. A. (2000). Determinants of chemical input use in peri-urban lowland systems : bivariate probit analysis in Cameroon. *Agricultural Systems*, *63*, 111–121.

Nubukpo, K. and Keita, M. S. (2006). Prix mondiaux, prix au producteur et avenir de la filiere coton au Mali. Cahiers Agricultures, *15*, 35–41.

Nwaru, J. C., Okoye, B. C. and Ndukwu, P. C. (2011). Measurement and determinants of production efficiency among small-holder sweet potato ( Ipomoea Batatas ) farmers in Ima State, Nigeria. *European Journal of Sienfitific Research*, *59*, 307–317.

Obi, A. (2013). Integration of crops and livestock in the smallholder farming system of the former homelands of South Africa. *Journal of Gricultural Science*, *5*(10), 183–198. http://doi.org/10.5539/jas.v5n10p183

OECD-FAO. (2016). *Agriculture in Sub-Saharan Africa : Prospects and challenges for the nest decade* (Vol. 59–96).

Ogada, M. J., Mwabu, G. and Muchai, D. (2014). Farm technology adoption in Kenya : a simultaneous estimation of inorganic fertilizer and improved maize variety adoption decisions. *Agricultural and Food Economics*, *2*(12), 1–18.

Okoboi, G. and Barungi, M. (2012). Constraints to fertilizer use in Uganda : Insights from Uganda census of agriculture 2008 / 9. *Journal of Sustainable Development*, *5*(10), 99–113. http://doi.org/10.5539/jsd.v5n10p99

Okoruwa, V., Jabbar, M. A. and Akinwumi, J. A. (1996). Crop-livestock competition in the West African derived savanna: Application of a multi-objective programming model. *Agricultural Systems*, *pp.439-453*(4), 439–453. http://doi.org/10.1016/S0308-521X(96)00005-4

Okoye, B. C., Abass, A., Bachwenkizi, B., Asumugha, G., Alenkhe, B., Ranaivoson, R., Ralimanana, I. (2016). Differentials in technical efficiency among smallholder cassava farmers in Central Madagascar : A Cobb Douglas stochastic frontier production approach. *Cogent Economics & Finance*, *13*(1), 1–10. http://doi.org/10.1080/23322039.2016.1143345

Okuyama, Y., Maruyama, A., Takagaki, M. and Kikuchi, M. (2017). Technical efficiency and production potential of selected cereal crops in Senegal. *Jouranl of Agriculture and Rural Developement in the Tropics and Subtropics*, *118*(2), 187–197.

Olayemi, A. O. (2012). Effects of family size on household food security in Osun State. *Asian Economic and Social Society*, *2*(2), 136–141.

Oltjen, J. W. and Beckett, J. L. (1996). Role of ruminant livestock in sustainable agricultural systems . *Journal of Animal Science*, *74*, 1406–1409.

Omiti, J. M. and Mccullough, E. (2009). Factors influencing the intensity of market participation by smallholder farmers : A case study of rural and peri-urban areas of Kenya. *African Journal of Agricultural Research*, *3*, 57–82.

Onoja, A. O., Usoroh, B. B., Adienne, D.and Deedam, N. J. (2012). Determinants of market participation in Nigerian small- scale fishery sector : Evidence from Niger Delta Region. *The Journal f Sustainable Development*, *9*, 69–84.

Onya, S. C., Okezie, C. A. and Ejiba, I. V. (2016). Determinants of Participation in Non-farm employment among rural farmers in Ebonyi State, Nigeria, *11*(6), 1–11. http://doi.org/10.9734/JSRR/2016/28047

Oyinbo, O. and Olaleye, K. T. (2016). Farm households livelihood diversification and poverty alleviation in Giwa local Gorvernment area of Kaduna state, Nigeria. *The Journal of Sustainable Development*, *15*, 219–232.

Partey, S. T., Zougmore, R. B., Ouedraogo, M. and Thevathasan, N. V. (2017). Why promote improved fallows as a climate-smart agroforestry technology in Sub-Saharan Africa ? *Sustainability MDPI*, *9*, 1–12. http://doi.org/10.3390/su9111887

Pienaar, L. and Traub, L. N. (2015). *Understanding the smallholder farmer in South Africa : Towards a sustainable livelihoods classification. International Conference of Agricultural Economists. pp36*.

Pitipunya, R. (1995). Determinants of crop diverisification on paddy field: A case study of diversification to vetetables. *Kasetsart Journal (Soc. Sci)*, *16*, 201–208.

Piya, L. and Lall, K. (2013). Determinants of adaptation practices to climate change by Chepang households in the rural Mid-Hills of Nepal. *Regional Environmental Change*, 437–447. http://doi.org/10.1007/s10113-012-0359-5

Place, F., Barrett, C. B., Freeman, H. A., Ramisch, J. J. and Vanlauwe, B. (2003). Prospects for integrated soil fertility management using organic and inorganic inputs : evidence from smallholder African agricultural systems. *Food Policy*, *28*, 365–378. http://doi.org/10.1016/j.foodpol.2003.08.009

Pratt, O. J. and Wingenbach, G. (2016). Factors affecting adoption of green manure and cover crop technologies among Paraguayan smallholder farmers. *Agroecology and Sustainable Food Systems*, *40*(10), 1043–1057. http://doi.org/10.1080/21683565.2016.1230568

Pretty, J., Toulmin, C. and Williams, S. (2011). Sustainable intensification in African agriculture. *International Journal of Agricultural Sustainability*, *9*(February), 5–24. http://doi.org/10.3763/ijas.2010.0583

Proctor, F. J. (2014). Rural economic diversification in sub-Saharan Afr*ica* (No. No.14632IED). London.

Rahman, S. (2001). Determinants of crop choices by Bangladeshi farmers : A Bivariate probit analysis. *Asian Journal of Agricultural and Development*, *5*, 29–41.

Rahman, S. and Chima, C. D. (2015). Determinants of modern technology adoption in multiple food crops in Nigeria : a multivariate probit approach. *International Journal of Agricultural Management*, *4*(3). http://doi.org/10.5836/ijam/2015-03-100

Rahut, D. B., Ali, A., Kassie, M. and Marenya, P. P. (2014). Rural livelihood diversification strategies in Nepal. *Poverty & Public Policy*, *6*(3), 259–277.

Rahut, D. B. and Scharf, M. M. (2012). Livelihood diversification strategies in the Himalayas *Journal of the Australian Agricultural and Resource Economics*, *56*, 558–582. http://doi.org/10.1111/j.1467-8489.2012.00596.x

Randela, R., Alemu, Z. G. and Groenewald, J. A. (2008). Factors enhancing market participation by small-scale cotton farmers. *Agrekon*, *47*(4), 451–469.

Randolph, T. F., Schelling, E., Grace, D., Nicholson, C. F., Leroy, J. L., Cole, D. C., … Ruel, M. (2014). Role of livestock in human nutrition and health for poverty reduction in developing countries. *Jouranl Animal Science*, 2788–2800. http://doi.org/10.2527/jas.2007-0467

Rao, P. P., Lagesh, M., Deb, U. K. and Jagadeesh, E. (2014). *T*ypology of agriculture for India Technology targeting and development planning. Dakha.

Reardon, T. (2001). Rural nonfarm employment and incomes in Latin America : Overview and policy implications. *World Development*, *29*(3).

Rios, R. A., Masters, A. W. and Shively, E. G. (2008). Linkages between market participation and productivity : results from a multi-Country farm household sample. Orlando, Florida.

Robels, R., De La Puente, T., Moran, J. and A, J. (2008). Typification and economic analysis of beef- producing farms in Spain. In *EAAE C*ongress People, Food and Environments: Global Trends and European Strategies.

Robles, R. R., Vannini, L. and Nistal, R. Á. (2005). Typification of dairy farms according to criteria of a socioeconomic nature : an illustration in " El Páramo " of Leon ( Spain ). In *European Association of Agricultural Economists Congress*. Copenhapen, Denmark.

Rudel, T. K., Kwon, O., Paul, B. K., Boval, M., Rao, I. M., Burbano, D., … Peters, M. (2016). Do smallholder, mixed crop-livestock livelihoods encourage sustainable agricultural practices? A Meta-Analysis. *Land MDPI*, *6*, 1–13. http://doi.org/10.3390/land5010006

Rufino, M. C., Tittonell, P., van Wijk, M. T., Castellanos-Navarrete, A., Delve, R. J., de Ridder, N. and Giller, K. E. (2007). Manure as a key resource within smallholder farming systems: Analysing farm-scale nutrient cycling efficiencies with the NUANCES framework. *Livestock Science*, *112*(3), 273–287. http://doi.org/10.1016/j.livsci.2007.09.011

Russelle, M. P., Entz, M. H. and Franzluebbers, A. J. (2007). Reconsidering integrated crop–livestock systems in North America. *Agronomy Journal*, *99*, 325–334. http://doi.org/10.2134/agronj2006.0139

Ryschawy, J., Choisis, N., Choisis, J. P., Joannon, A. and Gibon, A. (2012). Mixed crop-livestock systems : an economic and environmental-friendly way of farming ? Animal, *6*, 1722–1730. http://doi.org/10.1017/S1751731112000675

Sakana, N., Becker, M., Langensiepen, M. and Wijk, V. M. (2012). Typology of smallholder production systems in small East-African Wetlands. *Society of Wetland Scienstists*, *101–116*(33), 101–116. http://doi.org/10.1007/s13157-012-0355-z

Sanogo, K., Binam, J., Villamor, G. B. and Dodiomon, S. (2016). Farmers' perceptions of climate change impacts on ecosystem services delivery of parklands in southern Mali. *Agroforestry Systems*, 2–19. http://doi.org/10.1007/s10457-016-9933-z

Sanogo, O. M., Ridder, N. De and Keulen, H. Van. (2010). Diversite et dynamique des exploitations agricoles mixtes agriculture- elevage au sud du Mali. Cahiers Agricultures. *Cahiers Agricultures*, *19*, 185–193.

Sapkota, M., Joshi, N. P., Kattel, R. R. and Bajracharya, M. (2017). Technical efficiency and its determinants on maize seed production in Palpa District, Nepal. *Preprints*. http://doi.org/10.20944/preprints201705.0067.v1

Sasson, A. (2012). Food security for Africa : an urgent global challenge. *Agricultural & Food Security*, *1*, 1–16.

Savadogo, K. and Pietola, K. (1998). Adoption of improved land use technologies to increase food security in Burkina Faso : Relating animal traction , productivity , and non-farm income. *Agricutural Systems*, *58*(3), 441–464.

Schiere, J. B., Ibrahim, M. N. M. and Keulen, H. Van. (2002). The role of livestock for sustainability in mixed farming : criteria and scenario studies under varying resource allocation. *Agri. Ecosystems & Environment*, *90 (2002)*, 139–153.

Schwarze, S. and Zeller, M. (2005). Income diversification of rural households in Central Sulawesi , Indonesia. *Quarterly Journal of International Agriculture*, *44*(1), 61–73.

Sebatta, C., Mugisha, J., Katungi, E., Kashaaru, A. and Kyomugisha, H. (2014). Smallholder farmers ' decision and level of participation in the potato market in Uganda. *Mordern Economy*, *5*, 895–906.

Senadza, B. (2012). Non-farm income diversification in rural Ghana : Patterns and determinants. *African Development Review, 24*(3), 233–244.

Seng, K. (2016). The effects of market participation on farm households' food security in Cambodia: an endogenous switching approach (No. 69669). Munich Personal RePEc Archive. Waseda University, Japon.

Serra, R. (2012). Cotton sector in Mali: Explaining the puzzles. In Africa Power and Politics, 32p.

Seyoum, E. T., Battese, G. E. and Fleming, E. M. (2000). Technical efficiency and productivity of maize producers in eastern Ethiopia : a study of farmers within and outside the Sasakawa-Global 2000 project. *Agricultural Economics*, *19*(1998), 341–348.

Sharma, R. and Singh, G. (2015). Access to modern agricultural technologies and farmer household welfare : evidence from India. *Millennial Asia*, *6*, 19–43. http://doi.org/10.1177/0976399614563222

Sheahan, M. and Barrett, C. B. (2017). Ten striking facts about agricultural input use in Sub-Saharan Africa. *Food Policy, 67*, 12–25. http://doi.org/10.1016/j.foodpol.2016.09.010

Shiferaw, B., Kassie, M., Jaleta, M. and Yirga, C. (2014). Adoption of improved wheat varieties and impacts on household food security in Ethiopia. *Food Policy, 44*, 272–284. http://doi.org/10.1016/j.foodpol.2013.09.012

Shiferaw, B., Prasanna, B. M., Hellin, J.and Bänziger, M. (2011). Crops that feed the world. Past successes and future challenges to the role played by maize in global food security. *Food Security*, *3*, 307–327. http://doi.org/10.1007/s12571-011-0140-5

Sibhatu, K. T. and Qaim, M. (2017). Rural food security , subsistence agriculture , and seasonality. *PLOS One*, *12*, 1–15. http://doi.org/10.1371/journal.pone.0186406

Sissoko, F., Coulibaly, D., Cisse, O. and Dugue, P. (2013). Évaluation de l'arrière effet de la culture du coton sur la production céréalière en zone cotonnière du Mali. *Agritrop*, *2,* 149–160.

Sodjinou, E., Glin, L. C., Nicolay, G., Tovignan, S. and Hinvi, J. (2015). Socioeconomic determinants of organic cotton adoption in Benin, West Africa. *Agricultural and Food Economics*, *3*, 1–22. http://doi.org/10.1186/s40100-015-0030-9

Soumare, M. (2008). *Dynamique et Durabilite des systemes agraires a base de coton au Mali*. PhD, These Universite de Paris X Nanterre. France

Staatz, J., Kelly, V., Boughton, D., Sohlberg, M., Skidmore, M., Diarrah, C. O., … Sako, M. (2011). *Évaluation du secteur agricole du Mali*.

Suess-reyes, J. and Fuetsch, E. (2016). The future of family farming : A literature review on innovative, sustainable and succession-oriented strategies. *Journal of Rural Studies*, *47,* 117–140. http://doi.org/10.1016/j.jrurstud.2016.07.008

Sultana, N., Hossain, E. and Islam, K. (2015). Income diversification and household well-being : A Case study in rural areas of Bangladesh. *International Journal of Business and Economics Research*, *3*, 172–179. http://doi.org/10.11648/j.ijber.20150403.20

Tarekegn, K., Haji, J. and Tegegne, B. (2017). Determinants of honey producer market outlet choice in Chena District, southern Ethiopia : a multivariate probit regression analysis. *Agricultural and Food Economics*, *5*, 1–14. http://doi.org/10.1186/s40100-017-0090-0

Tefft, J. (2004). Bulding on successes in African Agriculure Mali's White Revolution: Smallholder cotton from 1960 to 2020 vision for food agriculture and the environment. *International Food Policy Research Institute*.

Teklewold, H., Kassie, M. and Shiferaw, B. (2013). Adoption of Multiple Sustainable Agricultural Practices in Rural Ethiopia. *Journal of Agricultural Economics*, *64*(3), 597–623. http://doi.org/10.1111/1477-9552.12011

Teklewold, H., Kassie, M., Shiferaw, B. and Köhlin, G. (2013). Cropping system diversification , conservation tillage and modern seed adoption in Ethiopia : Impacts on household income , agrochemical use and demand for labor. *Ecological Economics*, *93*, 85–93. http://doi.org/10.1016/j.ecolecon.2013.05.002

Theriault, V. and Serra, R. (2013). Institutional environment and technical efficiency : A Stochastic frontier analysis of cotton producers in West Africa. *Journal of Agricultural Economics*, 1–23. http://doi.org/10.1111/1477-9552.12049

Theriault, V., Serra, R. and Sterns, J. A. (2013). Prices, institutions, and determinants of supply in the Malian cotton sector. *Agricultural Economics*, *44*, 161–174. http://doi.org/10.1111/agec.12001

Theriault, V., Smale, M. and Haider, H. (2017). How does gender affect sustainable intensification of cereal production in the West African Sahel ? evidence from Burkina Faso. *World Development*, *92*, 177–191. http://doi.org/10.1016/j.worlddev.2016.12.003

Thornton, P. K. and Herrero, M. (2001). Integrated crop – livestock simulation models for scenario analysis and impact assessment. *Agricultural Systems*, *70*, 581–602.

Tijani, A. A. (2006). Analysis of the technical efficiency of rice farms in Ijesha land of Osun State, Nigeria. *Agrekon*, *45*(2), 126–135. http://doi.org/10.1080/03031853.2006.9523738

Tipi, T., Yildiz, N., Nargeleçekenler, M. and Çetin, B. (2017). Measuring the technical efficiency and determinants of efficiency of rice ( Oryza sativa ) farms in Marmara region, Turkey. *New Zealand Journal of Crop and Horticultural Science*, *37*(2), 121–129. http://doi.org/10.1080/01140670909510257

Tittonell, P. (2013). Livelihood strategies , resilience and transformability in African. *Agricultural Systems*. http://doi.org/10.1016/j.agsy.2013.10.010

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. http://doi.org/10.1016/j.agsy.2009.10.001

Todde, G., Murgia, L., Caria, M. and Pazzona, A. (2016). A multivariate statistical analysis approach to characterize mechanization, structural and energy profile in Italian dairy farms. *Energy Reports*, *2*, 129–134. http://doi.org/10.1016/j.egyr.2016.05.006

Traore, B. B., Wijk, M. T. V. A. N., Descheemaeker, K., Corbeels, M., Rufino, M. C.and Giller, K. E. (2015). Mali : Learning from farmer perceptions and on farm trials. *Expl Agriculure*, *51*, 615–634. http://doi.org/10.1017/S0014479714000507

Traore, B., Marc, C., Wijk, M. Van, Rufina, C. M. and Giller, K. E. (2013). Effects of climate variability and climate change on crop production in southern Mali. *European Journal of Agronomy*, 115–125. http://doi.org/10.1016/j.eja.2013.04.004

Vall, E., Dugu, P. and Blanchard, M. (2006). Le tissage des relations agriculture-elevage au fil du coton. *Cahiers Agricultures*, *15*(1), 72–79.

Vall, E., Koutou, M., Coulibaly, K., Diallo, M. A., Andrieu, N., Vall, E., … Di-, M. A. (2012). Intégration agriculture-élevage et intensification écologique dans les systèmes agrosylvopastoraux de l'Ouest du Burkina Faso, province du Tuy. *Hal*.

Van Eeckhout L. (2010). La faim a un peu reculé dans le monde. Le Monde 2010, pp 1:4

Vanlauwe, B., Coyne, D., Gockowski, J., Hauser, S., Huising, J., Masso, C., … Asten, P. Van. (2014). Sustainable intensification and the African smallholder farmer. *Current Opinion in Environmental Sustainability*, *8*, 15–22. http://doi.org/10.1016/j.cosust.2014.06.001

Vargas, M. A. and Campos, R. R. (2005). *Crop substitution and diversification strategies : empirical evidence from selected Brazilian Municipalities* (No. Paper No.28). Brazil.

Verkaart, S., Munyua, B. G., Mausch, K. and Michler, J. D. (2017). Welfare impacts of improved chickpea adoption : A pathway for rural development in Ethiopia ? *Food Policy*, *66*, 50–61. http://doi.org/10.1016/j.foodpol.2016.11.007

Wan, J., Li, R., Wang, W., Liu, Z. and Chen, B. (2016). Income diversification : A strategy for rural region risk management. *Sustainability MDPI*, 1–12. http://doi.org/10.3390/su8101064

Woldenhanna, T. and Oskam, A. (2001). Income diversification and entry barriers : evidence from the Tigray region of northern Ethiopia. *Food Policy*, *26*, 351–365.

Wooldridge, J. M. (2002). *Econometric Analysis of Cross Section and Panel Data*. pp 741

World, B. (2008). *Agriculture Development: World development report 2008,* *Washington,DC*.

Wossen, T., Abdoulaye, T., Alene, A., Haile, M. G., Feleke, S., Olanrewaju, A. and Manyong, V. (2017). Impacts of extension access and cooperative membership on technology adoption and household welfare. *Journal of Rural Studies*, *54*, 223–233. http://doi.org/10.1016/j.jrurstud.2017.06.022

Wossen, T., Berger, T. and Di Falco, S. (2015). Social capital , risk preference and adoption of improved farm land management practices in Ethiopia. *Agricultural Economics*, *46*, 81–97. http://doi.org/10.1111/agec.12142

Wossen, T., Berger, T., Mequaninte, T. and Alamirew, B. (2013). Social network effects on the adoption of sustainable natural resource management practices in Ethiopia. *International Journal of Sustainable Development & World Ecology*, *20*, 477–483. http://doi.org/10.1080/13504509.2013.856048

Xu, D., Zhang, J., Rasul, G., Liu, S., Xie, F., Cao, M. and Liu, E. (2015). Household livelihood strategies and dependence on agriculture in the mountainous settlements in the three Gorges Reservoir Area, China. *Sustainability*, *7*, 4850–4869. http://doi.org/10.3390/su7054850

Zalkuwi, J., Singh, R., Bhattarai, M., Singh, O., Tribhuvan and Singh, P.U. (2015). Possibility of improvement in Sorghum production : A comparative study of technical efficiency in India and Nigeria. *International Journal of Advances in Agricultural Science and Technology*, *2*(10), 1–12.

Zereyesus, Y. A., Shanoyan, A., Ross, K. L. and Amanor, V. (2016). The determinants of household-level well-being in Northern Ghana. *Development Studies Research*, *3*(1), 1–10. http://doi.org/10.1080/21665095.2016.1229128

Yamane, T. (1967). Statistics: An Introductory Analysis, 2nd Edition., New York: Harper and Row.

**QUESTIONNAIRE**

**Income and crop diversification strategies and agricultural practices in an integrated crop and livestock production system in Southern Mali.**

**Please read the following consent form**

My name is **Bandiougou DEMBELE,** Junior Scientist Research Assistant. I am collecting information here in your community for the above topic. I would like to ask you to participate in a one on one interview, to help us in assessing income diversification in an integrated agricultural production system. I request you to answer all questions truthfully and voluntarily. You may refuse to participate and that will not affect your family. However I hope that this research will benefit Mali by improving policies implemented by the government towards the agriculture sector which forms the backbone of the economy.

If you have any questions about this study, you may ask.

Date : ___/___ /2016 ***N° Agricultural exploitation I___I___I___I*** Code Village I___I___I Name Village __________

**1. General information**

| | | |
|---|---|---|
| **Head of family (HF)** | Name | |
| **Sex** : 1= Male ; 0 = Female | | |
| **Age :** | | |
| **Type CMDT[1]:** | | |
| **Education level** : 1=none ; 2=Primary ; 3=Secondary; 4= high school | | |
| **Marital status** : 1=Married ; 2=single ; 3=Divorce | | |
| **Religion**: 1=Christian ; 2=Muslim ; 3= none | | |
| **Origin** : 1=Native ; 0=Immigrant | | |
| **Commune** : | | |
| **Provincial :** | | |

**Type CMDT[1]: (A, B, C and D)**

Main activity of HF (that gives revenue): …………………… I____I and secondary activity of HF (that gives revenue): …………..…………..…..……….. I____I

**Codes**: 1= Agriculture, 2= Livestock, 3= fishery, 4= Forestry exploitation 5 = other to precise

How has he become head of family? ………………………. …………………..............

Succession ❒

Separation ❒

Migration ❒

**2. Population**

How many households do you have in the family?:…………………..

| Men adult (15 years and +) | Women adult 15years and +) | children (10 to 14 years ) | Children less than 10 years | Total |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| | | | | |

Does agricultural exploitation need an external worker for agricultural activities? I___I (0=No, 1=Yes)

if No explain why: …………………………………………………………………………

**3. Characterization of land**

| Field | Surface (ha) | Ownership status<br>1=Property<br>0=Hire | Location (soil type) |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |

| | |
|---|---|
| Do women of the family have a field? 1=Yes ; 0=No | |
| If Yes, how many hectare (s)? | ha |

Does farming family has a fallow?................ 1= Yes, No =0 if Yes................ ha and Age............

Does farming family has a land reserve?................ 1= Yes, No =0 if Yes................ ha

**4. Horticulture farming practices**

**4.1. Vegetables farming**

Do you sell vegetable product? ……….1=Yes, 0 =No

| Crops _Name | Hectare (ha) | Production (kg) | Quantity sold(kg) | Amount (FCFA) |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |

**Crops name**: 1= cabbage 2= onions, 3= Tomatoes, 4= Potatoes, 5= sweet potatoes, 6= lettuce

4.2. Horticulture farming

Do you sell horticultural product? ……….1=Yes, 0 =No

| Tree _Name | Hectare (ha) | Production | Quantity sold | amount (FCFA) |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |

**Tree**:1=Mango, 2=Oranges, 3=Papaya, 4= Banana , 5=cashew , 6=other (to precise)..................................

Do you sell food crop production for family expenditure? ............1= Yes, 0=No

| Crops | Quantity sold (kg) | Amount (CFA) | Utilization of money |
|---|---|---|---|
| Maize | | | |
| Sorghum | | | |
| Millet | | | |

Cotton revenue ……………………………………………….(CFA)

**Major constraints**
Tick Yes =1 /No = 0

| | |
|---|---|
| Low soil fertility | |
| Climate conditions (low rainfall) | |
| Low use of agricultural input | |
| Crops pests and deseases | |
| access to agricultural extension services | |
| Limited access to agricultural credit | |
| High cost of agricultural input (fertilizer, herbicides, insectides…) | |
| Poor infrastructure (road) | |
| Low prices of agricultural products | |

**5. Agricultural equipment**

| **Equipment for draught animals** | Number | **Motorized material** | Number | **Vehicles and others** | Number |
|---|---|---|---|---|---|
| Plough | | Tractor | | Van/lorry | |
| Sower | | Motorcultivator | | Car | |
| Multiplough | | Mill | | Motorbike | |
| Donkey cart | | Other1……………. | | Solar | |
| Ox cart | | Other2…………… … | | TV | |
| Other1………………… … | | | | Mobile phone | |
| Other2………………… … | | | | radio | |

Are you hiring equipment for ploughing? : ……..(0=No, 1: Yes )
If yes which equipment ………….....1= draught ox, 2= plough, 3= tractor;
Total amount paid……………………Fcfa.

**6. Livestock composition**

| **Cattle** | **Number** | **Other livestock** | **Number** |
|---|---|---|---|
| Draught oxen | | Sheep | |
| Bull | | Goats | |
| Cows | | Donkeys | |
| Bull calf | | Horses | |
| Heifer | | Pigs | |
| Calves | | Poultry *(estimation)* | |

**OBJECITVE of breeding cattle (bovine)**
Revenue ❒
Organic matter ❒
Draught power ❒

Milk production ❒
Do you practice transhumance (pastoralism)? : …………… (0=No, 1: Yes)
If yes, since when ………………. if no why
…………………...........................................................................................................
.................................................................................................................................
...............................................................................................................................
Reasons for pastoralism…………………………………………………………………….
………………………………………………………………………………………….
………………….............................................................................................................
If yes, month of departure ………….............; Month of back …………………….................
If yes, which destination? ………………….. (Province /regions/country)
Does farming family buy the input for livestock? ………. *(0=No, 1: Yes)*

| **Input** | **Quantity** | **Price Unit*** | **Total amount** | **Source of money** |
|---|---|---|---|---|
| Vaccination | | | | |
| Feeding (fodders) | | | | |
| Salt | | | | |
| Bran | | | | |
| Concentrated feeding | | | | |

Do you sell cattle for family expenditure? ......................1= Yes, 0=No

| Livestock (cattle) | **Number sold** | **Amount (FCFA)** | **Utilisation of money** |
|---|---|---|---|
| Draught oxen | | | |
| Bull | | | |
| Bull calf | | | |
| Cows | | | |
| Heilfer | | | |

**Manure Production**
Do you produce manure? ……… *(0=No, 1: Yes).*
If No why: ..……………………………………..................... ……………………..............................

**7. Food security**
Quantity of cereals intake per day

| | In dry season | In rainy season |
|---|---|---|
| Major cereals consumed ? | | |
| Which quantity of cereals do you give daily for cooking? | Name: ……………….<br>Quantity in kg/day<br>……………....... | Name: …………………........<br>Quantity in kg/day<br>……….…..... |
| On average, how many people eat here daily? | | |
| How many meals per day? | | |

Does your cereal production cover the annual food? I____I 1=Always (all years), 2= Almost all time except the bad years 3= only if year is good, 4=Never.
Do you sell the cereals during harvesting I___I 0=No, 1=Yes
Do you purchase during difficult periods: I___I 0=No, 1=Yes
For three last years, how many months, did you have shortage of food

| Years | Number of month of shortage | Give the reasons and then code* |
|---|---|---|
| 2013 | I_____I | I____I I____I |
| 2014 | I_____I | I____I I____I |
| 2015 | I_____I | I____I I____I |

* **Reasons** (several possible codes) : Code : 0. No shortage , 1. Drought, 2. Insects attack, 3.lack of land, 4. Excess of rain, 5.Insufficiency of force worker, 6.Insufficiency of equipment, 7.No enough input, 8.other (to precise)

**8. Forest Products income**

| **Forest products sold** | **(FCFA)** |
|---|---|
| Timber | |
| Fruit | |
| Charcoal | |
| Oil (Shea/karite) | |
| Honey | |
| Other1 | |
| Other2 | |

**9. Non-agricultural activities income**

| **Extra-agricultural activity** | **Earn (FCFA)** | **Extra-agricultural activity** | **Earn (FCFA)** |
|---|---|---|---|
| Traditional Gold mining | | Private salary | |
| handcraft activities | | Public salary | |
| Informal trade | | Retirement /pension | |
| Transport activities | | Other (to precise) | |
| Hunting activities | | | |

**10. Institutional factors**

Does farming family has access to agricultural credit?................ 1=Yes, No=0
If No
why...................................................................................................................................
.......................................................................................................................................
.....
Does farming family has access to extension services?................ 1=Yes, No=0

If No
why.........................................................................................................................
...............................................................................................................................
.....

**11. Agricultural technology practices**

N° Plot ____________________Hectare (ha)_____________

Crop name _______________ improved seed: _____1= Yes, 0= No

Applied organic matter: __________1= Yes, 0= No

Plough and handsowing __________1= Yes, 0= No

Plough and sower __________1= Yes, 0= No

Applied inorganic fertilizer: __________1= Yes, 0= No

Operation farming

| Type of operations | No. of men per day | No. of women per day | Total family workers | Total external workers | Amount (FCFA) |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| ---------------- | | | | | |
| -------------- | | | | | |
| -------------- | | | | | |

Cropping operation (continued)

| | Date | No. of men per day | No. of women per day | Total family workers | Total external workers | Amount (FCFA) |
|---|---|---|---|---|---|---|
| 1st Weeding | | | | | | |
| 2nd Weeding | | | | | | |
| 3 th weeding | | | | | | |
| ------------- | | | | | | |
| -------------- | | | | | | |

**12. Crops inputs**

| Input | Unit (kg) or liter | Quantity | Unit Price | Total amount | Mode of payment |
|---|---|---|---|---|---|
| NPK cotton | | | | | |
| NPK cereals | | | | | |
| Urea | | | | | |
| DAP | | | | | |
| Herbicide | | | | | |
| Insecticide | | | | | |
| Fungicide | | | | | |
| Seed | | | | | |
| Other 1……… | | | | | |
| Other 2……… | | | | | |

**13. Chemical fertilization application**

| Name | No men per day | No women per day | Total workers family | Total workers external | Amount (FCFA) |
|---|---|---|---|---|---|
| NPK Cotton | | | | | |
| NPK Cereals | | | | | |
| Urea | | | | | |
| ------------- | | | | | |

**Harvesting**

| **Type culture** | No. of men per day | No. of women per day | Total family workers | Total external workers | Amount (FCFA) |
|---|---|---|---|---|---|
| | | | | | |

Total production ____________________ (kg)

# Appendix

Multivariate probit (SML, # draws = 5) Number of obs = 134
Wald chi2(48) = 139.12
Log pseudolikelihood = -262.26522 Prob > chi2 = 0.0000

| | Coef. | Robust Std. Err. | z | P>\|z\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| **cereals** | | | | | | |
| familysize | -.0084408 | .0074395 | -1.13 | 0.257 | -.0230219 | .0061404 |
| ratiodep1 | -.5279958 | .6877249 | -0.77 | 0.443 | -1.875912 | .8199203 |
| age | .0059861 | .0088931 | 0.67 | 0.501 | -.0114441 | .0234162 |
| lextserv | -.1443361 | .3680681 | -0.39 | 0.695 | -.8657364 | .5770641 |
| accesscredit | -.1855255 | .3161125 | -0.59 | 0.557 | -.8050945 | .4340436 |
| lncash | .0276689 | .0269568 | 1.03 | 0.305 | -.0251655 | .0805032 |
| lnofffarm | .0138341 | .0265736 | 0.52 | 0.603 | -.0382492 | .0659175 |
| Edu_form | .3627545 | .2678998 | 1.35 | 0.176 | -.1623194 | .8878285 |
| hcostagriinput | -.4111415 | .3731549 | -1.10 | 0.271 | -1.142512 | .3202285 |
| poorinfras | -.171002 | .2625558 | -0.65 | 0.515 | -.6856018 | .3435979 |
| lpriceagriprdt | .1987453 | .3481793 | 0.57 | 0.568 | -.4836736 | .8811641 |
| land_owneship | .4108322 | .3284339 | 1.25 | 0.211 | -.2328865 | 1.054551 |
| _cons | .2600637 | .8030645 | 0.32 | 0.746 | -1.313914 | 1.834041 |
| **veget** | | | | | | |
| ratiodep1 | 1.589822 | .8900425 | 1.79 | 0.074 | -.1546294 | 3.334273 |
| familysize | .0071509 | .0078719 | 0.91 | 0.364 | -.0082778 | .0225795 |
| age | .0005521 | .0109787 | 0.05 | 0.960 | -.0209658 | .0220699 |
| lextserv | -1.164113 | .4100604 | -2.84 | 0.005 | -1.967817 | -.3604099 |
| accesscredit | 1.028508 | .3540784 | 2.90 | 0.004 | .3345273 | 1.722489 |
| lncash | .1026913 | .0436681 | 2.35 | 0.019 | .0171033 | .1882793 |
| lnofffarm | -.0983913 | .028911 | -3.40 | 0.001 | -.1550558 | -.0417269 |
| Edu_form | -.2421028 | .257197 | -0.94 | 0.347 | -.7461995 | .261994 |
| hcostagriinput | .4612156 | .4063396 | 1.14 | 0.256 | -.3351954 | 1.257626 |
| poorinfras | .9200568 | .2605349 | 3.53 | 0.000 | .4094178 | 1.430696 |
| lpriceagriprdt | -.9669981 | .4001274 | -2.42 | 0.016 | -1.751233 | -.1827628 |
| land_owneship | .5849106 | .3466165 | 1.69 | 0.092 | -.0944454 | 1.264267 |
| _cons | -2.3031 | 1.170229 | -1.97 | 0.049 | -4.596708 | -.0094922 |
| **catte** | | | | | | |
| ratiodep1 | .1732116 | .84679 | 0.20 | 0.838 | -1.486466 | 1.83289 |
| familysize | .0216043 | .0091069 | 2.37 | 0.018 | .0037552 | .0394535 |
| age | .020081 | .0100486 | 2.00 | 0.046 | .0003862 | .0397758 |
| lextserv | .1183105 | .3498039 | 0.34 | 0.735 | -.5672925 | .8039134 |
| accesscredit | .4203383 | .3108881 | 1.35 | 0.176 | -.1889912 | 1.029668 |
| lncash | .0396353 | .0349575 | 1.13 | 0.257 | -.0288802 | .1081507 |
| lnofffarm | .0008362 | .0278803 | 0.03 | 0.976 | -.0538082 | .0554806 |
| Edu_form | .632876 | .277794 | 2.28 | 0.023 | .0884098 | 1.177342 |
| hcostagriinput | -.3395852 | .3039045 | -1.12 | 0.264 | -.935227 | .2560567 |
| poorinfras | .285591 | .2445275 | 1.17 | 0.243 | -.193674 | .764856 |
| lpriceagriprdt | -.1646205 | .3516921 | -0.47 | 0.640 | -.8539244 | .5246835 |
| land_owneship | .5861748 | .3471103 | 1.69 | 0.091 | -.0941489 | 1.266499 |
| _cons | -3.322756 | 1.07526 | -3.09 | 0.002 | -5.430227 | -1.215285 |
| **hort** | | | | | | |
| ratiodep1 | .7563999 | .7765387 | 0.97 | 0.330 | -.7655879 | 2.278388 |
| familysize | .0061105 | .0084237 | 0.73 | 0.468 | -.0103995 | .0226206 |
| age | .0056398 | .0080858 | 0.70 | 0.485 | -.010208 | .0214876 |
| lextserv | -.448591 | .3689719 | -1.22 | 0.224 | -1.171763 | .2745806 |
| accesscredit | .2650632 | .3135336 | 0.85 | 0.398 | -.3494513 | .8795778 |
| lncash | .0314019 | .0296947 | 1.06 | 0.290 | -.0267987 | .0896025 |
| lnofffarm | .0222139 | .0267253 | 0.83 | 0.406 | -.0301667 | .0745944 |
| Edu_form | -.4654326 | .2450114 | -1.90 | 0.057 | -.9456462 | .0147809 |
| hcostagriinput | .7273344 | .3358486 | 2.17 | 0.030 | .0690832 | 1.385586 |
| poorinfras | -.5895367 | .2489331 | -2.37 | 0.018 | -1.077437 | -.1016368 |
| lpriceagriprdt | -.2884232 | .3403528 | -0.85 | 0.397 | -.9555025 | .378656 |
| land_owneship | .4128901 | .3793757 | 1.09 | 0.276 | -.3306726 | 1.156453 |
| _cons | -2.022201 | .8591532 | -2.35 | 0.019 | -3.706111 | -.3382919 |
| /atrho21 | -.1806936 | .152905 | -1.18 | 0.237 | -.4803818 | .1189946 |
| /atrho31 | .1384809 | .1258054 | 1.10 | 0.271 | -.1080931 | .3850549 |

| | Coef. | Std. Err. | z | P>\|z\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| /atrho41 | .3600572 | .1394284 | 2.58 | 0.010 | .0867826 | .6333318 |
| /atrho32 | -.5020188 | .2331471 | -2.15 | 0.031 | -.9589787 | -.045059 |
| /atrho42 | .3398853 | .1468466 | 2.31 | 0.021 | .0520713 | .6276993 |
| /atrho43 | -.0642256 | .1656587 | -0.39 | 0.698 | -.3889108 | .2604596 |
| rho21 | -.1787524 | .1480193 | -1.21 | 0.227 | -.4465493 | .1184361 |
| rho31 | .1376024 | .1234233 | 1.11 | 0.265 | -.107674 | .3670893 |
| rho41 | .3452644 | .1228075 | 2.81 | 0.005 | .0865654 | .5603421 |
| rho32 | -.4637034 | .1830156 | -2.53 | 0.011 | -.743821 | -.0450285 |
| rho42 | .327375 | .1311084 | 2.50 | 0.013 | .0520243 | .556466 |
| rho43 | -.0641374 | .1649773 | -0.39 | 0.697 | -.3704208 | .2547253 |

Likelihood ratio test of rho21 = rho31 = rho41 = rho32 = rho42 = rho43 = 0:
chi2(6) = 19.459 Prob > chi2 = 0.0035

```
Multinomial logistic regression                 Number of obs     =        134
                                                LR chi2(30)       =     119.72
                                                Prob > chi2       =     0.0000
Log likelihood = -107.98651                     Pseudo R2         =     0.3566
```

| cod_strat | Coef. | Std. Err. | z | P>\|z\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| Cot_Maize | | | | | | |
| age | .3082709 | .1518574 | 2.03 | 0.042 | .0106359 | .6059058 |
| familysize | 1.170609 | .5486584 | 2.13 | 0.033 | .095258 | 2.245959 |
| Edu_form | 4.574352 | 3.710539 | 1.23 | 0.218 | -2.698171 | 11.84688 |
| ox | 2.897865 | 1.60855 | 1.80 | 0.072 | -.2548347 | 6.050565 |
| lnnonfarm | .3224587 | .2468246 | 1.31 | 0.191 | -.1613087 | .8062261 |
| lagriinput | -3.236728 | 2.749304 | -1.18 | 0.239 | -8.625265 | 2.151808 |
| hcostagriinput | -4.710613 | 5.644269 | -0.83 | 0.404 | -15.77318 | 6.351951 |
| lnincome_pers | .4997146 | .2727102 | 1.83 | 0.067 | -.0347876 | 1.034217 |
| cropspest | -4.852384 | 3.128932 | -1.55 | 0.121 | -10.98498 | 1.280209 |
| lextserv | -6.514385 | 1008.582 | -0.01 | 0.995 | -1983.298 | 1970.269 |
| _cons | -21.1667 | 1008.683 | -0.02 | 0.983 | -1998.15 | 1955.816 |
| Cereals_only | (base outcome) | | | | | |
| Cot_3cereals | | | | | | |
| age | .2858028 | .1508748 | 1.89 | 0.058 | -.0099064 | .5815119 |
| familysize | 1.166862 | .5480153 | 2.13 | 0.033 | .0927715 | 2.240952 |
| Edu_form | 8.591363 | 3.666623 | 2.34 | 0.019 | 1.404914 | 15.77781 |
| ox | 3.257912 | 1.618264 | 2.01 | 0.044 | .0861726 | 6.429652 |
| lnnonfarm | .3678076 | .2495957 | 1.47 | 0.141 | -.121391 | .8570063 |
| lagriinput | -2.360071 | 2.779453 | -0.85 | 0.396 | -7.807698 | 3.087557 |
| hcostagriinput | -6.879187 | 5.628008 | -1.22 | 0.222 | -17.90988 | 4.151507 |
| lnincome_pers | .5032233 | .2579226 | 1.95 | 0.051 | -.0022958 | 1.008742 |
| cropspest | -4.735648 | 3.14891 | -1.50 | 0.133 | -10.9074 | 1.436103 |
| lextserv | -5.293847 | 1008.581 | -0.01 | 0.996 | -1982.077 | 1971.489 |
| _cons | -22.15918 | 1008.683 | -0.02 | 0.982 | -1999.141 | 1954.823 |
| Cot_2cereals | | | | | | |
| age | .2965573 | .1509019 | 1.97 | 0.049 | .0007951 | .5923196 |
| familysize | 1.135264 | .5477369 | 2.07 | 0.038 | .0617195 | 2.208809 |
| Edu_form | 7.611847 | 3.660379 | 2.08 | 0.038 | .4376365 | 14.78606 |
| ox | 3.331018 | 1.617023 | 2.06 | 0.039 | .1617105 | 6.500325 |
| lnnonfarm | .3976648 | .2498441 | 1.59 | 0.111 | -.0920207 | .8873503 |
| lagriinput | -2.698814 | 2.77104 | -0.97 | 0.330 | -8.129952 | 2.732324 |

```
 hcostagriinput |  -6.650407   5.630772    -1.18   0.238    -17.68652    4.385704
  lnincome_pers |   .3935037   .2440991     1.61   0.107    -.0849216    .8719291
      cropspest |  -5.422789   3.147759    -1.72   0.085    -11.59228    .7467062
       lextserv |   -6.14839   1008.581    -0.01   0.995    -1982.932    1970.635
          _cons |   -20.0981   1008.682    -0.02   0.984    -1997.078    1956.882
---------------------------------------------------------------------------------
```

vif

```
    Variable |       VIF       1/VIF  
-------------+----------------------
  familysize |      2.12    0.472063
          ox |      2.08    0.481130
         age |      1.26    0.796003
lnincome_p~s |      1.17    0.852743
   lnnonfarm |      1.14    0.877886
  lagriinput |      1.14    0.878114
   cropspest |      1.11    0.899908
    Edu_form |      1.11    0.900449
hcostagrii~t |      1.11    0.900530
    lextserv |      1.08    0.925781
-------------+----------------------
    Mean VIF |      1.33
```

Cotton (SFA)

```
Stoc. frontier normal/half-normal model         Number of obs     =        126
                                                Wald chi2(5)      =      16.15
Log likelihood = -35.389293                     Prob > chi2       =     0.0064

-----------------------------------------------------------------------------------
       lnyield_ha |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
------------------+----------------------------------------------------------------
lnyield_ha        |
      lnhect_plot |  -.0821268   .0618611    -1.33   0.184    -.2033723    .0391187
         lnNKP_ha |   .3621577    .091776     3.95   0.000     .1822802    .5420353
        lnUera_ha |  -.1184627   .1432005    -0.83   0.408    -.3991306    .1622051
   lnLabour_total |   .0228033     .04465     0.51   0.610    -.0647091    .1103157
    lnqtot_insect |   .0116007   .0376823     0.31   0.758    -.0622553    .0854567
            _cons |   5.898663   .6580653     8.96   0.000     4.608878    7.188447
------------------+----------------------------------------------------------------
lnsig2v           |
frenquence_insect |   .4032388   .1928865     2.09   0.037     .0251881    .7812894
   freqen_weeding |  -2.558671   .7274018    -3.52   0.000    -3.984352   -1.132989
            _cons |  -.8533981   .9601336    -0.89   0.374    -2.735225    1.028429
------------------+----------------------------------------------------------------
lnsig2u           |
              age |  -.0353514   .0149073    -2.37   0.018    -.0645692   -.0061337
       familysize |   .0302507   .0147019     2.06   0.040     .0014355     .059066
    land_owneship |   .2729713   .6163614     0.44   0.658    -.9350749    1.481017
         Edu_form |   .0771176   .3784153     0.20   0.839    -.6645628     .818798
         lextserv |   .2492568   .7276398     0.34   0.732    -1.176891    1.675404
     accesscredit |  -.2879264   .5165921    -0.56   0.577    -1.300428    .7245755
               ox |  -.1506206   .1378214    -1.09   0.274    -.4207455    .1195043
        tools_eqp |  -.1247783   .1460547    -0.85   0.393    -.4110403    .1614837
-----------------------------------------------------------------------------------
```

Maize SFA

```
Stoc. frontier normal/half-normal model         Number of obs     =        133
                                                Wald chi2(4)      =   2.80e+10
Log likelihood = -47.251848                     Prob > chi2       =     0.0000

------------------------------------------------------------------------------
  lnha_yield |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
lnha_yield   |
   lnfalbour |   .0421844   1.67e-06  2.5e+04   0.000     .0421811    .0421877
       lnNPK |    .342504   2.37e-06  1.4e+05   0.000     .3424993    .3425086
```

| | | | | | | |
|---|---|---|---|---|---|---|
| lnUrea | -.0259192 | 9.68e-07 | -2.7e+04 | 0.000 | -.0259211 | -.0259173 |
| lnPlot_ha | -.0286344 | 2.69e-06 | -1.1e+04 | 0.000 | -.0286397 | -.0286292 |
| _cons | 6.445331 | .0000142 | 4.5e+05 | 0.000 | 6.445303 | 6.445358 |
| **lnsig2v** | | | | | | |
| _cons | -36.9127 | 304.0601 | -0.12 | 0.903 | -632.8596 | 559.0342 |
| **lnsig2u** | | | | | | |
| age | .0031349 | .0090047 | 0.35 | 0.728 | -.0145139 | .0207837 |
| familysize | -.0025701 | .0100413 | -0.26 | 0.798 | -.0222508 | .0171106 |
| accesscredit | -.3761597 | .3327051 | -1.13 | 0.258 | -1.02825 | .2759303 |
| ox | -.074645 | .0746569 | -1.00 | 0.317 | -.2209699 | .0716798 |
| Educ_Level_d3 | .4546832 | .2808773 | 1.62 | 0.105 | -.0958263 | 1.005193 |
| lextserv | -.8046491 | .3908614 | -2.06 | 0.040 | -1.570723 | -.0385748 |
| lagriinput | .6518541 | .2787196 | 2.34 | 0.019 | .1055736 | 1.198135 |
| lnonfarmincoVF | -.1004344 | .085071 | -1.18 | 0.238 | -.2671705 | .0663017 |
| lnofffarm | .0726553 | .0278078 | 2.61 | 0.009 | .018153 | .1271575 |
| hect_plot | -.0100951 | .0661122 | -0.15 | 0.879 | -.1396726 | .1194824 |
| _cons | -.2397588 | 1.104258 | -0.22 | 0.828 | -2.404064 | 1.924546 |
| sigma_v | 9.65e-09 | 1.47e-06 | | | 3.8e-138 | 2.5e+121 |

Maize (agricultural practices)
Multivariate probit (SML, # draws = 5)  Number of obs = 133
Wald chi2(44) = 96.02
Log likelihood = -243.67536  Prob > chi2 = 0.0000

| | Coef. | Std. Err. | z | P>\|z\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| **Seed_impr** | | | | | | |
| age | .0038836 | .0089741 | 0.43 | 0.665 | -.0137052 | .0214725 |
| lnlabour | .0252102 | .1626904 | 0.15 | 0.877 | -.2936571 | .3440776 |
| ox | -.1391131 | .09508 | -1.46 | 0.143 | -.3254666 | .0472403 |
| accesscredit | .0307412 | .3027472 | 0.10 | 0.919 | -.5626324 | .6241149 |
| Tools_eq | .1324042 | .0814142 | 1.63 | 0.104 | -.0271646 | .291973 |
| lnhect_plot | -.8064716 | .1970908 | -4.09 | 0.000 | -1.192763 | -.4201807 |
| lextserv | -.2561509 | .3674014 | -0.70 | 0.486 | -.9762444 | .4639426 |
| freq_weed | .2282573 | .2666676 | 0.86 | 0.392 | -.2944016 | .7509161 |
| land_owneship | .5411696 | .3756169 | 1.44 | 0.150 | -.1950261 | 1.277365 |
| lnofffarm | .0140836 | .0280937 | 0.50 | 0.616 | -.040979 | .0691462 |
| Edu_form | .4129192 | .2639549 | 1.56 | 0.118 | -.1044229 | .9302612 |
| _cons | -1.23399 | .9872588 | -1.25 | 0.211 | -3.168982 | .7010018 |
| **org_matter_apply** | | | | | | |
| age | -.0022067 | .0085245 | -0.26 | 0.796 | -.0189145 | .0145011 |
| lnlabour | .0730997 | .1545473 | 0.47 | 0.636 | -.2298075 | .3760069 |
| ox | -.0122231 | .0698223 | -0.18 | 0.861 | -.1490723 | .1246261 |
| lnhect_plot | -.2202611 | .1847269 | -1.19 | 0.233 | -.5823192 | .141797 |
| Tools_eq | .1384786 | .0706912 | 1.96 | 0.050 | -.0000735 | .2770307 |
| accesscredit | .0390285 | .2883785 | 0.14 | 0.892 | -.5261829 | .6042398 |
| lextserv | -.1776136 | .3454781 | -0.51 | 0.607 | -.8547382 | .4995111 |
| freq_weed | -.4099604 | .2541963 | -1.61 | 0.107 | -.908176 | .0882552 |
| land_owneship | .8780111 | .3886962 | 2.26 | 0.024 | .1161806 | 1.639842 |
| lnofffarm | .0012904 | .026215 | 0.05 | 0.961 | -.05009 | .0526708 |
| Edu_form | -.1310456 | .2477135 | -0.53 | 0.597 | -.6165551 | .3544638 |
| _cons | -1.110165 | .9731234 | -1.14 | 0.254 | -3.017452 | .7971219 |
| **Hand_sowing** | | | | | | |
| age | .004675 | .0092329 | 0.51 | 0.613 | -.0134212 | .0227711 |
| lnlabour | .1048883 | .1686533 | 0.62 | 0.534 | -.225666 | .4354427 |
| ox | .0414783 | .0794356 | 0.52 | 0.602 | -.1142127 | .1971693 |
| lnhect_plot | -.7229737 | .2095011 | -3.45 | 0.001 | -1.133588 | -.312359 |
| accesscredit | .8745351 | .3327794 | 2.63 | 0.009 | .2222994 | 1.526771 |
| lextserv | .2291048 | .4143669 | 0.55 | 0.580 | -.5830395 | 1.041249 |
| freq_weed | .9748837 | .2875302 | 3.39 | 0.001 | .411335 | 1.538432 |

| | Coef. | Std. Err. | z | P>\|z\| | [95% Conf. Interval] | |
|---|---|---|---|---|---|---|
| land_owneship | .3034363 | .362141 | 0.84 | 0.402 | -.4063471 | 1.01322 |
| lnofffarm | -.0700478 | .0339816 | -2.06 | 0.039 | -.1366504 | -.0034451 |
| Tools_eq | .1636431 | .0789903 | 2.07 | 0.038 | .008825 | .3184612 |
| Edu_form | .1657641 | .2649856 | 0.63 | 0.532 | -.3535981 | .6851264 |
| _cons | -1.438852 | .9141604 | -1.57 | 0.115 | -3.230574 | .3528691 |
| Plough_sowing | | | | | | |
| age | -.000145 | .0079687 | -0.02 | 0.985 | -.0157634 | .0154735 |
| lnlabour | -.1610519 | .1463876 | -1.10 | 0.271 | -.4479662 | .1258625 |
| ox | -.0938196 | .0793946 | -1.18 | 0.237 | -.2494302 | .061791 |
| lnhect_plot | .4830999 | .1697712 | 2.85 | 0.004 | .1503544 | .8158455 |
| accesscredit | -.3908806 | .2764468 | -1.41 | 0.157 | -.9327065 | .1509452 |
| lextserv | -.1376323 | .3205594 | -0.43 | 0.668 | -.7659172 | .4906525 |
| freq_weed | -.9265918 | .2480501 | -3.74 | 0.000 | -1.412761 | -.4404226 |
| land_owneship | -.4091969 | .2949367 | -1.39 | 0.165 | -.9872622 | .1688684 |
| lnofffarm | .0486814 | .0262491 | 1.85 | 0.064 | -.0027659 | .1001287 |
| Tools_eq | -.1599323 | .0762232 | -2.10 | 0.036 | -.309327 | -.0105375 |
| Edu_form | -.2875085 | .2664813 | -1.08 | 0.281 | -.8098022 | .2347852 |
| _cons | 2.264724 | .858522 | 2.64 | 0.008 | .5820519 | 3.947396 |
| /atrho21 | .3238334 | .1550694 | 2.09 | 0.037 | .0199029 | .6277639 |
| /atrho31 | -.2628209 | .1824339 | -1.44 | 0.150 | -.6203847 | .0947429 |
| /atrho41 | .1993001 | .1514041 | 1.32 | 0.188 | -.0974464 | .4960467 |
| /atrho32 | .4232817 | .1888138 | 2.24 | 0.025 | .0532134 | .7933499 |
| /atrho42 | -.3398497 | .1404636 | -2.42 | 0.016 | -.6151533 | -.0645462 |
| /atrho43 | -1.912232 | .3634285 | -5.26 | 0.000 | -2.624538 | -1.199925 |
| rho21 | .312969 | .1398804 | 2.24 | 0.025 | .0199003 | .5565106 |
| rho31 | -.2569321 | .1703907 | -1.51 | 0.132 | -.5513959 | .0944605 |
| rho41 | .1967026 | .145546 | 1.35 | 0.177 | -.0971391 | .4590024 |
| rho32 | .3996914 | .1586502 | 2.52 | 0.012 | .0531633 | .6603025 |
| rho42 | -.3273432 | .1254124 | -2.61 | 0.009 | -.5477444 | -.0644567 |
| rho43 | -.9572725 | .0303933 | -31.50 | 0.000 | -.9895502 | -.8336317 |

Likelihood ratio test of rho21 = rho31 = rho41 = rho32 = rho42 = rho43 = 0:
chi2(6) = 72.0045 Prob > chi2 = 0.0000

Bivariate probit (sorghum_ practice)

Bivariate probit regression                    Number of obs = 57
                                               Wald chi2(22) = 37.66
Log likelihood = -40.344157                    Prob > chi2 = 0.0200

| | Coef. | Std. Err. | z | P>\|z\| | [95% Conf. Interval] | |
|---|---|---|---|---|---|---|
| Mode_sowing | | | | | | |
| age | -.0376763 | .0189199 | -1.99 | 0.046 | -.0747587 | -.0005939 |
| familysize | .0186777 | .0144625 | 1.29 | 0.197 | -.0096684 | .0470237 |
| ox | -.1337706 | .179863 | -0.74 | 0.457 | -.4862956 | .2187544 |
| Tools_eq | -.1281915 | .1420915 | -0.90 | 0.367 | -.4066858 | .1503028 |
| Edu_form | -.3639152 | .4956942 | -0.73 | 0.463 | -1.335458 | .6076276 |
| accesscredit_01 | .3095643 | .5090716 | 0.61 | 0.543 | -.6881976 | 1.307326 |
| lextserv_01 | .4855987 | .6416594 | 0.76 | 0.449 | -.7720307 | 1.743228 |
| hect_plot | .408368 | .3722275 | 1.10 | 0.273 | -.3211844 | 1.13792 |
| hcostagriinput | .8673058 | .6523822 | 1.33 | 0.184 | -.4113399 | 2.145951 |

```
 lnonfarmincoVF |   .0278592   .0670921     0.42   0.678    -.1036389    .1593574
      lnofffarm |  -.0346388    .039853    -0.87   0.385    -.1127493    .0434717
          _cons |   .8296827    1.16654     0.71   0.477    -1.456694    3.116059
----------------+----------------------------------------------------------------
inorg_fer       |
            age |   .0089268    .023529     0.38   0.704    -.0371892    .0550428
     familysize |  -.0230332   .0198046    -1.16   0.245    -.0618495    .0157832
             ox |  -.6307031   .2218733    -2.84   0.004    -1.065567   -.1958394
       Tools_eq |   .6924035   .2012752     3.44   0.001     .2979113    1.086896
       Edu_form |   1.585123   .6922033     2.29   0.022     .2284299    2.941817
accesscredit_01 |  -1.450789   .7692304    -1.89   0.059    -2.958453    .0568753
    lextserv_01 |  -.7529064   1.074975    -0.70   0.484    -2.859818    1.354005
      hect_plot |    .457778   .4102342     1.12   0.264    -.3462663    1.261822
 hcostagriinput |  -1.445999   .6622676    -2.18   0.029     -2.74402   -.1479786
 lnonfarmincoVF |   -.060786   .1162615    -0.52   0.601    -.2886544    .1670823
      lnofffarm |   .0748595   .0531853     1.41   0.159    -.0293817    .1791007
          _cons |  -2.254181   1.846223    -1.22   0.222    -5.872712     1.36435
----------------+----------------------------------------------------------------
        /athrho |  -14.57526   774.6332    -0.02   0.985    -1532.829    1503.678
----------------+----------------------------------------------------------------
            rho |         -1   6.78e-10                            -1           1
---------------------------------------------------------------------------------
LR test of rho=0: chi2(1) = 10.881                        Prob > chi2 = 0.0010
```

**Agricultural technologies practices (dependent variables)**

Cotton: organi matter applied under cotton plot

```
. tab org_matter_apply (dependent variable)

    organic |
     Matter |      Freq.     Percent        Cum.
------------+-----------------------------------
         No |         44       34.92       34.92
        Yes |         82       65.08      100.00
------------+-----------------------------------
      Total |        126      100.00
```

Maize: agricultural practices (dependent variable)

```
. tab Improved seed

Improved_se |
         ed |      Freq.     Percent        Cum.
------------+-----------------------------------
         No |         85       63.91       63.91
        Yes |         48       36.09      100.00
------------+-----------------------------------
      Total |        133      100.00

. tab org_matter_apply

 Org Matter |
    apllied |      Freq.     Percent        Cum.
------------+-----------------------------------
         No |         79       59.40       59.40
        Yes |         54       40.60      100.00
------------+-----------------------------------
      Total |        133      100.00

. tab Plough +sowing

Sowing_Plou |
         gh |      Freq.     Percent        Cum.
------------+-----------------------------------
         No |         88       66.17       66.17
        Yes |         45       33.83      100.00
------------+-----------------------------------
```

```
      Total |        133      100.00
```

```
. tab Plough + Hand sowing

 Model_hand |
     Sowing |      Freq.     Percent        Cum.
------------+-----------------------------------
         No |         36       27.07       27.07
        Yes |         97       72.93      100.00
------------+-----------------------------------
      Total |        133      100.00
```

Millet: agricultural practices
  tab Type_sowing

```
Sowing type |      Freq.     Percent        Cum.
------------+-----------------------------------
         No |         50       79.37       79.37
        Yes |         13       20.63      100.00
------------+-----------------------------------
      Total |         63      100.00
```

```
. tab applied_fert

Application |
Fertlisatio |
          n |      Freq.     Percent        Cum.
------------+-----------------------------------
         No |         36       57.14       57.14
        Yes |         27       42.86      100.00
------------+-----------------------------------
      Total |         63      100.00
```

Sorghum: agricultural practices

tab Mode_sowing

```
Sowing+Plou |
         gh |      Freq.     Percent        Cum.
------------+-----------------------------------
         No |         42       73.68       73.68
        Yes |         15       26.32      100.00
------------+-----------------------------------
      Total |         57      100.00
```

```
. tab inorg_fer

  Inorganic |
fert_applie |
          d |      Freq.     Percent        Cum.
------------+-----------------------------------
         No |         43       75.44       75.44
        Yes |         14       24.56      100.00
------------+-----------------------------------
      Total |         57      100.00
```