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By Jeanne Yekeleya Coulibaly

Entitled
DIVERSIFICATION OR COTTON RECOVERY IN THE MALIAN COTTON ZONE: EFFECTS ON HOUSEHOLDS AND WOMEN

For the degree of Doctor of Philosophy

Is approved by the final examining committee:

John H. Sanders
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Paul Preckel

Timothy Baker

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# DIVERSIFICATION OR COTTON RECOVERY IN THE MALIAN COTTON ZONE: EFFECTS ON HOUSEHOLDS AND WOMEN

A Dissertation

Submitted to the Faculty

of

Purdue University

by

Jeanne Yekeleya Coulibaly

In Partial Fulfillment of the

Requirements for the Degree

of

Doctor of Philosophy

December 2011

Purdue University

West Lafayette, Indiana

To my parents Albert and Rosalie, my brothers and sisters and my daughter Odile

# ACKNOWLEDGEMENT

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# ABSTRACT

Jeanne, Coulibaly Yekeleya. Ph.D., Purdue University, December 2011. Diversification or Cotton Recovery in the Malian Cotton Zone: Effects on Households and Women.

This dissertation investigates income diversification alternatives from the cotton economy and compares those initiatives with present policy measures to restore the cotton sector in Mali. It also derives the welfare implications for women of these various policy measures.

During the decade preceding 2011, farmers' incomes in the cotton zone of Mali have been significantly affected by the downturn of the cotton economy explained by many factors including the low farm gate cotton price, the declining cotton yields and soil fertility concerns. In 2011, the Malian government substantially increased the farm gate cotton price as a result of the world cotton price hikes and to stimulate a revival of the domestic cotton industry. Also for the main crops, farmers had access to a 24 percent fertilizer subsidy relatively to the market price as the government wants to intensify agricultural production by improving soil fertility levels and raising crop yields.

With a farm household model that allows producers to make decisions at several points in time, we evaluated farmers' response to the government cotton pricing policy and compared the income effect resulting from this latter policy with the adoption of improved agricultural sorghum technologies plus marketing strategies. Then, we further simulated the effects of the elimination of the fertilizer subsidy and the predicted reduction in cotton farm gate price by 8 percent because the economic conditions of 2011 are expected to be temporary. The welfare implications on women of these various policies were lastly derived.

Results showed that the substantial increase in cotton prices and access to fertilizer subsidy are very effective policies that will substantially boost the expansion of cotton area and farmers' incomes. Maize will also benefit significantly from the increase in cotton farm gate price. With the availability of the improved sorghum technologies and marketing strategies, farmers' incomes are further enhanced by 21 percent leading to more income diversification. The expected 8 percent decline in the cotton price will essentially be detrimental to cotton production as farmers will divert cotton land and fertilizer use to sorghum. Moreover, the removal of the fertilizer subsidy will seriously constrain intensive crop production and result in a sizable reduction in household wealth by 21 percent but diversification into sorghum will become an important part of the crop mix.

Overall, the most profitable economic opportunity for the household is not the most beneficial for women. Women are made better off with the adoption of less labor intensive technologies on the communal plot. So, there is need to focus more on women's specific welfare enhancing policies including access to better lands and inputs, reduction of their labor requirements in agriculture and household activities.

# LIST OF ACRONYMS

BNDA= Banque Nationale de Developpement Agricole

DAP= Diammonium Phosphate (18-46-0)

FCFA= Franc de la Communauté Financière Africaine

CMDT= Compagnie Malienne de Développement du Textile

CIMMYT=International Maize and Wheat Improvement Center

FAO= Food and Agriculture Organization

IER= Institut d'Economie Rurale

IMF= International Monetary Fund

INTSORMIL= International Sorghum and Millet Collaborative Research Support Program

Ha= Hectare

Kg= Kilogram

Lb= Pounds

NPK= Nitrogen, Phosphate, Potassium Complex Fertilizer (15-15-15)

NPKSB= Nitrogen, Phosphate, Potassium, Sulfur, Boron Complex Fertilizer

(14-18-18-1-6)

OMA= Observatoire du Marché Agricole

PDE= Person-Day-Equivalent

INERA= Institut de l'Environement et de Recherches Agricoles

# CHAPTER 1: INTRODUCTION

## 1.1. Problem Statement

Agricultural technology introduction and marketing strategies are the main policies to stimulate agricultural growth in sub-Saharan countries. In these countries, agricultural development is constrained by low soil fertility, but water management techniques and improved cultivars are also critical (Sanders et al. 1996). Hence, it is not surprising that research programs have emphasized the diffusion of technologies based on inorganic fertilizers, high yielding varieties, and water retention techniques.

In Southern Mali, diffusion of new varieties of sorghum cultivars combined with increasing use of fertilizer and water retention techniques have been growing during the past decades to respond to soil fertility constraints (Ayele and Wield 2005). This diffusion process for new technologies of cereals (maize and sorghum) has also accelerated recently with farmers' disillusion from declining world cotton prices before 2010 (Baquedano et al. 2010). The downward trend in the world cotton price was due to the cost reduction and output expansion effects due to the introduction of transgenic cotton, Bt cotton in the major cotton producers, combined with the reduction of the system of guaranteed cotton price by the Malian parastatal company (Droy 2008) as well as the competition from synthetics.

The declining cotton price has encouraged Malian farmers to move away from cotton to cereal technologies including sorghum. Farmers are diversifying away from cotton through an increase in area and improved inputs allocated to the production of cereals. In the cotton zone, cotton production and area cultivated over the past decade has dramatically decreased by 80 percent (see figure 2.1) while maize and sorghum areas have increased by 143 and 18 percent[1] (Malian Ministry of Agriculture, 2010). Some of the fertilizer allocated as credit for cotton is presently being diverted to cereals especially maize but including sorghum.

However, limited access to financial resources and cereal price collapses at harvest, have an impact on farmers' willingness to adopt new cereal technologies. Farmers operate in an environment characterized by variability in rainfall and grain market price collapses (Vitale and Sanders 2005). There are three types of price collapses faced by staples in developing countries.[2] These three price collapses reduce the expected prices, hence the expected incomes. Hence, marketing strategies to moderate or eliminate the price collapses are expected to increase the incentive to introduce new technologies.

In 2010, the world cotton market experienced a historic price spike characterized by an 80 percent increase compared to the world price in 2009 (ICAC 2010). This price surge is explained by the adverse impact of flood on cotton production in China, one of the largest cotton producers and consumers. Thus, the Malian government decided to raise the farm gate cotton price by 36 percent[3] in nominal terms for the 2011 crop season. This price increase had no precedent in the history of cotton in Mali over the past 15 years. Through this price policy the government expects to stimulate a large supply response from producers and revamp the domestic cotton industry.

Also, with the potential increased income following adoption of new technologies and marketing innovations in cereals, there is a need to investigate how decisions are made within the household and the impact of the increased income on women's welfare. A large body of literature argues that women may not benefit from adoption of

[1] Millet area has even doubled during the last decade, which is a symptom here of soil fertility depletion.

[2] Prices collapse annually at harvest because famers need cash then and generally have limited storage availability. Prices collapse in good and sometimes even normal rainfall years because there are few alternative markets for food staples and an inelastic demand for them. In poor rainfall years when prices start increasing rapidly, governments frequently intervene and drive down prices. Then the question is: Without a marketing strategy to overcome some of these price collapses, when can farmers make money?

[3] In 2011, the price has been raised to 255 F CFA/kg from the 185 F CFA/kg in 2010. The exchange rate presently (May 2011) is 452 F CFA/kg.

agricultural technologies on the communal family land because of the additional labor requirements thereby reducing their labor available for their main source of income "women's private plots" (Kumar 1987, Gladwin and McMillan 1989, Lilja and Sanders 1998). In fact, the positive effects from technological change on the communal land on women's income may be reduced or eliminated by the decrease in labor availability for their private plots.[4]

Thus, there are two main problems addressed in this dissertation. First, what are the household income effects of further diversification of the cotton economy and how do these compare with the present and potential policy measures being implemented to revamp the cotton economy? Secondly, how would these various changes in technology, marketing and policy affect the welfare of women (and by implication children)?

## 1.2 Objectives

The specific objectives of this thesis are:

1. Estimate the income effect of the government cotton pricing policy and fertilizer subsidy program. These are the innovations of Malian cotton policy in 2011.
2. What happens to the cotton sector and to diversification when the cotton price comes back down to its recent levels and the fertilizer subsidy on cotton is eliminated?
3. Evaluate the impact of new sorghum technology and better marketing practices on household income. Besides the yield effect following the adoption of improved agricultural technology, farmers have been recommended various new marketing strategies. What is the impact of these technology and marketing changes individually and collectively?
4. Estimate the impact of fertilizer subsidies on the adoption of sorghum technology-marketing policy and on household incomes. In 2011, the fertilizer subsidy program was extended to sorghum and millet as opposed to the previous years where it only targeted

[4] However, a complete welfare analysis would need also to consider the welfare benefits to women from the increased household expenditures made possible by the technological change.

maize, cotton and rice. We consider the impact of the technology-marketing changes with the addition of this fertilizer subsidy and what happens when it is removed.

5. Estimate the welfare implications for women from the adoption of improved sorghum technology-marketing innovations and the changes in the cotton policy.

## 1.3 Organization of the Research

This dissertation is organized as follows:

After the introduction, a descriptive analysis of farm production systems and socio-economic characteristics of farm households in the geographical setting is presented in the second chapter. Next, the third chapter lays out the improved sorghum technologies and marketing strategies diffused by the IER-INTSORMIL program in Mali. These technologies and marketing strategies will be the center of our analysis in this research work. The fourth chapter develops the modeling framework and data used to analyze the income effects of agricultural policies and marketing strategies. We discuss the stochastic environment in which farmers make their decisions by analyzing variability in yields and prices with secondary aggregate data. A stochastic sequential programming model is used as the modeling framework and the model results are discussed in three consecutive chapters. From these results, the welfare implications regarding the impact of the cotton policy and sorghum technology-marketing innovation on women are analyzed in the eighth chapter. Lastly, the conclusion and policy implications of the research work are presented in a final chapter.

# CHAPTER 2: DESCRIPTIVE ANALYSIS OF THE STUDY AREA

## 2.1. Introduction

This chapter analyzes the farm production system and socio-economic characteristics of the farm households in the study area. The farming and economic characteristics of the households in the study area will be used to construct the modeling framework and to validate the model's results in subsequent chapters. The analysis is based on farm household data collected during a field survey for the crop year 2008/2009 and data consistency was checked during additional field visits in 2010 and 2011. The primary data collection was complemented by aggregate data in the study area. The chapter begins by presenting the geographical location, land use and soils types of the study area. Then, it documents the traditional cropping systems of the average farm household and the cotton farm gate price fixation mechanism. In a third section, the chapter discusses the traditional crop yields in the study area and issues of fertilizer supply. The chapter ends by analyzing the demographic and economic characteristics of the sample surveyed.

## 2.2. Geographical Location, Land Use and Soil Types

The Koutiala cercle (equivalent French name in Mali for district) is located in the Sikasso region of southern Mali near the neighboring countries of Ivory Coast and Burkina Faso. This cercle is an old cotton zone. The rapid population growth has resulted in an extension of area cultivated and an increase in the livestock herd size in order to meet the increasing demand for food. The long time practice of cotton culture and unsustainable land management has led to soil depletion and a reduction in the traditional fallow systems (Kaya and Nair 2001). Land in the Koutiala cercle is a scarce resource.

So, the resulting land scarcity combined with the poor quality of soils in the district make imperative the introduction and diffusion of intensive technologies.

This is why since 2006, the IER-INTSORMIL project has disseminated in many villages of the cercle, an improved technological package of sorghum composed of high-yielding sorghum cultivars, moderate use of fertilizer and intensive agricultural practices. The village of study selected for this research is Garasso. This village is the most successful site for the adoption and diffusion of the sorghum technologies in Koutiala.

In Garasso sorghum is produced on all three topographic levels: plateau, slope and lowlands. The soils range from clay, loam sandy and sandy soils. Sandy soils have very low organic matter and infiltration capacity. Due to their poor level of fertility and poor water retention capacity, sandy soils are mainly cropped to millet which tolerates better low soil fertility and water scarcity than the other crops and is concentrated on the plateau and slopes. Clay and loam sandy soils are of higher quality and sorghum responds better in these soils. They are used to cultivate cotton, maize and sorghum often grown in rotation.

## 2.3 Traditional Cropping Systems and Cotton Farm Gate Price

The crop season in the study area starts usually with the first rains which occur generally in the end of May. The agricultural campaign takes place during the rainy season. It starts in June with the planting activities and ends in December by the harvest.

The traditional crops grown by farmers are sorghum, millet, maize, cotton, peanut and cowpea. Cotton is the first crop to be planted in June followed by maize and the other grains and beans. Maize harvest occurs in August and September prior to the other crops' harvest which is realized from October to December. Maize is considered to be a "soudure" (hungry season) crop because it can be consumed during the period before harvest when the food supply is most scarce.

The results in table 2.1 show that currently, the average farm size is estimated at 15 hectares per household. Under the traditional technologies, farmers on average allocate 4 hectares of land to cotton, 5 ha of sorghum, 3 hectares to maize and millet. Half a hectare is devoted to peanut. Cowpea is not often grown by farmers. Those who do plant it allocate very small areas of land and use the harvest to feed animals. The new sorghum cultivar is grown on a pilot land of one hectare on average. So, the main crops cultivated in the farming system are cotton, maize, sorghum and millet and they will be the core crops that will be analyzed in the farm model.

Table 2.1: Areas and Yields of the Main Crops Cultivated in the Crop Year 2008/2009

| Crops | Area cultivated in hectare | Yields (kg/ha) |
|---|---|---|
| Cotton | 4.2 | 1,278 |
| Maize | 2.8 | 1,789 |
| Traditional Sorghum | 3.4 | 1,376 |
| Improved sorghum | 1.3 | 1,658 |
| Millet | 2.8 | 1,276 |
| Peanut | 0.5 | 544 |
| Cowpea | 0 | |
| Total | 15.1 | |

Source: Primary Survey Data
Sample: 57 farmers interviewed

Garasso, like the other villages in the cercle of Koutiala, has been traditionally a cotton growing area. During the flourishing years of cotton, from 1970 to the end of the 1990s, cotton was by far the main cash crop in the farming system. Since the end of the 1990s, the cotton economy has become less competitive with the declining world cotton prices and the reduction of agricultural subsidy in the Malian cotton industry. Cotton area and production have dropped by 80 percent in the decade from 1998 to 2008 (see figure 2.1) whereas the area planted for sorghum and millet have respectively increased by 18 percent and more than 100 percent (Malian Ministry of Agriculture 2009). The increase in areas for the cereals as represented in figure 2.2 reflects an increasing productivity for these crops. Moreover, presently with the collapse of the cotton economy, producers are diversifying away from cotton and are becoming increasingly interested in growing intensively maize, sorghum[5] and millet for consumption and marketing.

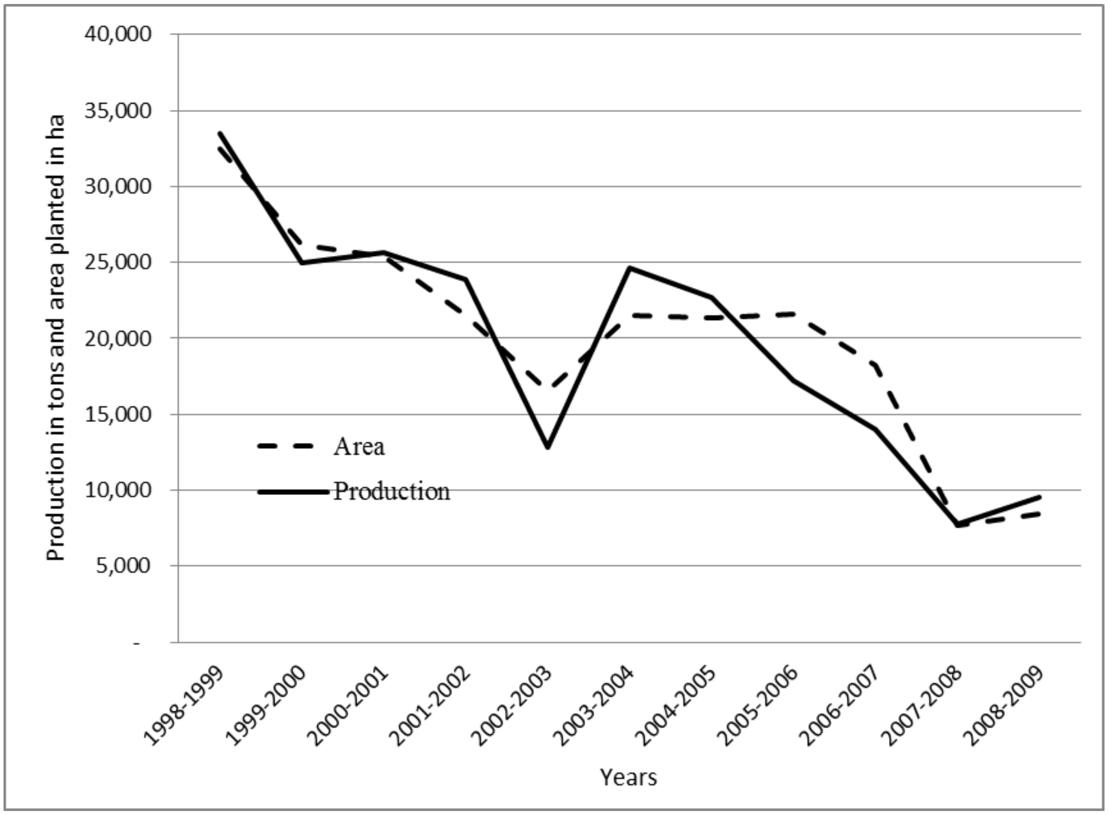


Figure 2.1: Cotton Area and Production in Koutiala (Mali), from 1998 to 2008. Source: Ministry of Agriculture, Mali

[5] Traditionally sorghum has been considered a subsistence crop a type of insurance policy for poor yields of millet. Increasingly there are new markets for sorghum as a food and feed.

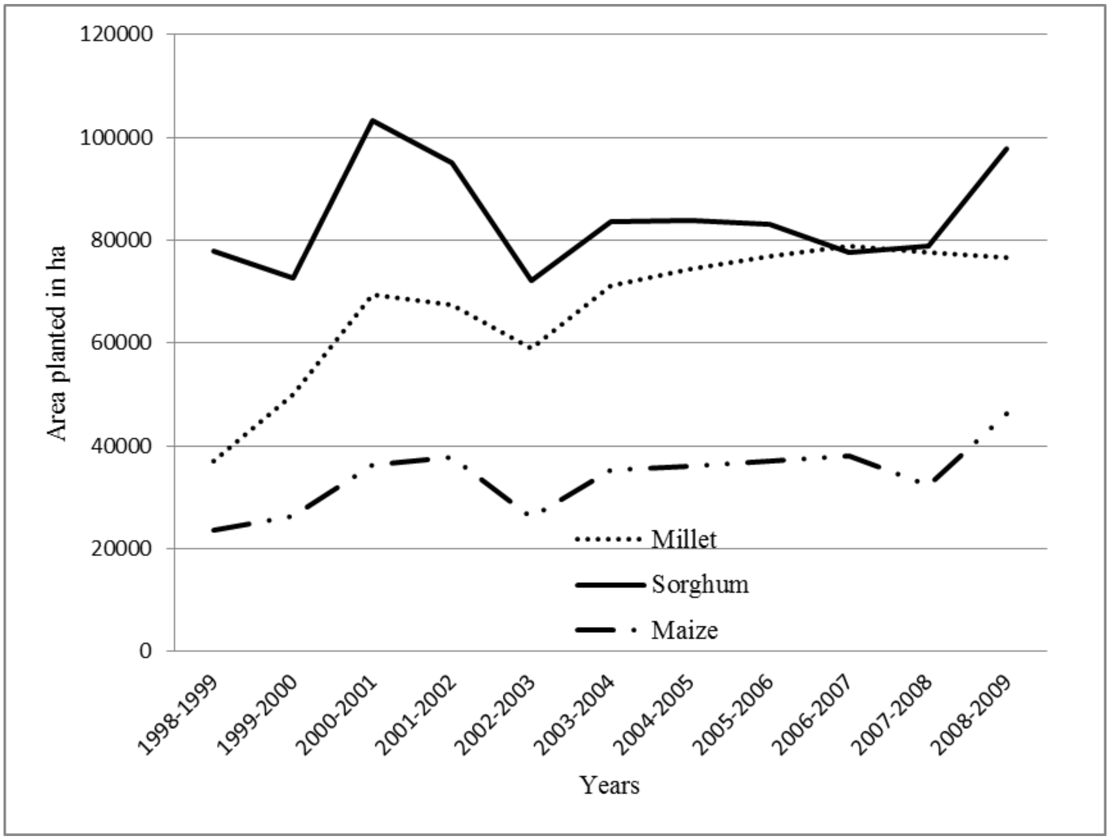


Figure 2.2: Area Planted to Sorghum, Millet and Maize from 1998 to 2008 in Koutiala (Mali)

Source: Ministry of Agriculture, Mali

The farm gate cotton price in Mali plays a key role in farmers' land allocation and has been generally dependent on the variations in the world cotton market. The farm gate cotton price is fixed at the beginning of the cropping season by the CMDT, (Compagnie Malienne de Développement du Textile). The CMDT is a parastatal cotton company in charge of research, extension and marketing of cotton since 1974. This company is primarily focused on the cotton industry and supplies production inputs on credit to cotton producers and purchases the cotton production after harvest. The CMDT purchases 4 to 5 months after harvest the cotton seed at a pan-territorial guaranteed price announced at the beginning of the planting season. Cotton seed is then ginned by the CMDT ginning companies and sold in international markets.

The price fixing process for cotton evolved over time. From 1974 to 1989 prices were fixed by the government solely. Then, from 1989 to 2004, farmers ’organizations became engaged in the negotiation process and a minimum guaranteed cotton seed purchase price was established. The minimum guaranteed cotton price was fixed at 200 F CFA/kg ($US/kg 0.44) and at 210 F CFA/kg ($US/kg 0.46) for the top quality cotton seed. In 2005, with donors’ pressure on the Malian government, the CMDT and farmers’organisations defined a new policy directly linking the farm gate cotton prices in Mali to the international cotton price. However, the full variation in the international cotton price was not transmitted directly to Malian farmers (Baquedano et al. 2010). Some agreements between the CMDT and the representatives of farmers’organizations specified the share of the international cotton price that will be paid to farmers and that kept by the CMDT for any investment and management expenditures. The farm gate price paid to farmers depends on their negotiation power and the government legislation on the cotton seed price floor and price ceiling (Nubukpo and Keita 2005). With this new policy, the cotton price ranged between 160 F CFA/kg ($US/kg 0.35) and 200 F CFA/kg up to the crop year 2010-2011 when the cotton price was raised to 231 F CFA/kg ($US/kg 0.51) following a spike in the world cotton market. This unprecedented increase in the world market resulted from poor harvest and demand expansion in China. Figure 2.3 below traces variation in the real price[6] of the farm gate cotton seed from 1980 to 2011. We can easily identify the downward trend in prices from the 1990s up to the recent year of 2011 characterized by the upswing of the cotton seed price. It is needless to say that cotton farmers’ incomes have been also significantly reduced over the period of declining cotton prices.

A central concern of this thesis is the impact of cereal technology introduction from the various prices for cotton. In the long run we expect Mali to continuously lose market share if it does not adopt Bt cotton as is already being done in more than 40 percent of world cotton production.

[6] The real cotton seed price has been obtained by deflating the nominal prices using the GDP deflator with 2008 as the base year. Deflating the nominal cotton seed prices with the fertilizer prices would have been ideal. But we didn’t have fertilizer prices for a very long time series (1980 to 2009).

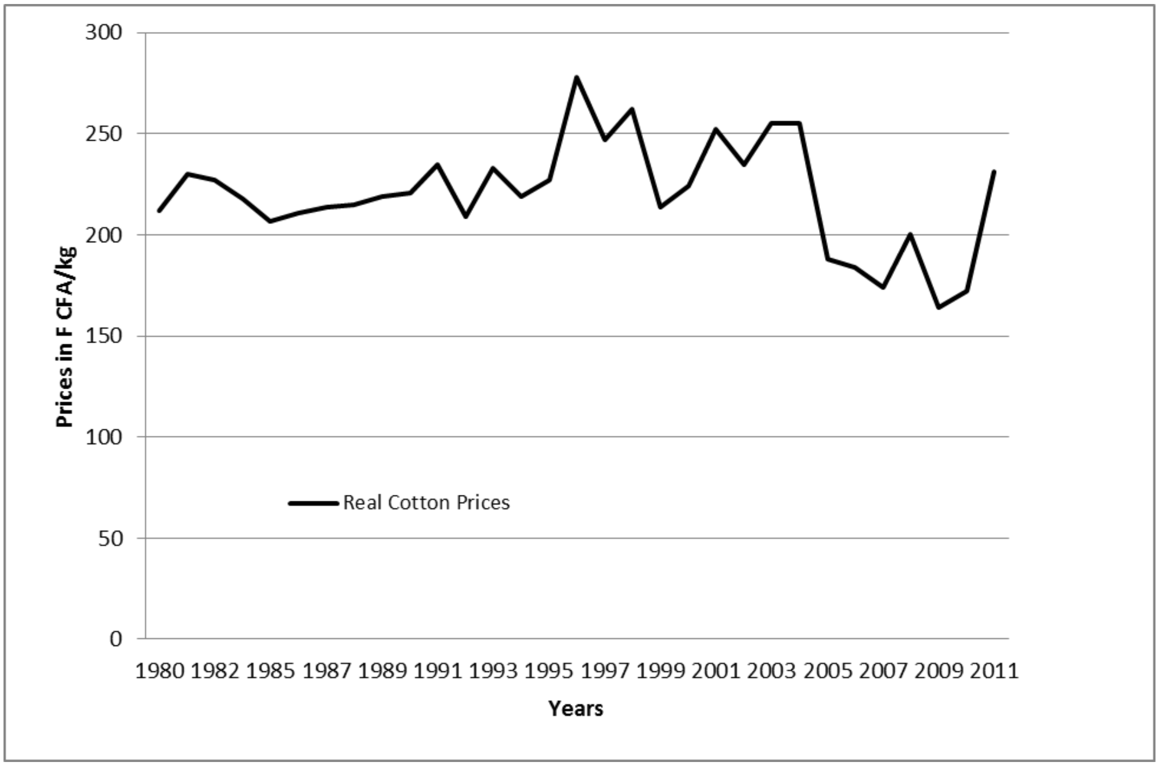


Figure 2.3: Real Cotton Prices in Mali from 1980 to 2011 (Base Year=2008)
Source: CMDT

## 2.4. Traditional Crop Yields and Fertilizer Supply

Crop yields depend on soil fertility as well as on the annual amount and distribution of rainfall. Under the traditional technologies, maize and cotton principally benefit from the application of inorganic fertilizer on a regular basis. Traditionally, 150 kg/ha of NPK, 50 kg/ha of Urea, 3l/ha of herbicide and 2 l/ha of insecticide are applied on cotton field. Maize receives 100 kg/ha of NPK and Urea as well as 2l/ha of herbicide. Since cotton and maize are the only crops that benefit from chemical fertilizer in the traditional farming system, it is expected that competition will take place between these two crops in the demand for fertilizer.

The fertilizer inputs for maize and production inputs for cotton (seeds, fertilizer, herbicide and pesticides) are supplied by the CMDT. In addition to the cotton sector, the CMDT has for two decades extended the supply of fertilizer loans to cereals, principally maize which is very demanding of plant nutrients and weed control. Farmers are required to reimburse the input credit for both cotton and cereals in cotton value after harvest. The loan reimbursement constraint will be a key component of the model formulation since it will have an impact on farmers land allocation.

The CMDT purchases fertilizer from private suppliers and delivers the inputs to farmers at the farm gate. Transportation costs are paid by the CMDT. Farmers have the opportunity to purchase fertilizer directly from private suppliers. However, the input loans from the CMDT do not require the farmers to pay transportation or transaction costs. Also, the access to input loans releases the liquidity constraint that farmers often face for the input purchase at the beginning of the cropping season.

The cost of fertilizer supplied by the CMDT is generally dependent on market prices and government fertilizer policy. Over the past decade, the nominal price of NPK has increased at an annual average rate of 8 percent, the Urea price has risen by 7 percent per year, insecticides prices were almost constant whereas the herbicides prices increased by 6 percent per year (Diakite et al. 2009). But in 2008, fertilizer (NPK and Urea) costs spiked in Mali as in the rest of the world. Fertilizer costs in 2008 were 40 percent higher than the cost in 2006. This surge in the price of fertilizer was due to a boom in the world demand for cereals and oil. The sharp increase of the world fertilizer prices halted in 2009 and 2010 but during those years the Malian government subsidized the cost of fertilizer for cotton and maize while fertilizer for sorghum and millet remained at their market prices.

In 2011, the fertilizer subsidy program was extended to sorghum and millet. The market prices for fertilizer during that latter year rose steadily to resume with their climb, similarly to the world market. Table 2.2 reports the cost of fertilizer for cotton and cereals supplied by the CMDT over the five past years. The fertilizer subsidy program will undoubtedly increase yields and stimulate area expansion but in the international context of fewer government interventions, this policy might not be very sustainable in the long run. It will therefore be interesting to investigate with the model the effects with and without the fertilizer subsidy program on farmers’ decision making and income.

Table 2.2: Cotton Prices in Real Terms and Fertilizer Costs supplied by CMDT from 2007 to 2011

| Years | Cotton Prices | Fertilizer Costs for Cotton | | Fertilizer Costs for Cereals | |
|---|---|---|---|---|---|
| | (F CFA/kg) | NPKBS (F CFA/kg) | Urea (F CFA/kg) | NPK (F CFA/kg) | Urea (F CFA/kg) |
| 2007 | 174 | 283 | 242 | 259 | 242 |
| ($/kg) | ( 0.38) | ( 0.63) | ( 0.53) | ( 0.57) | ( 0.53) |
| 2008 | 200 | 369 | 380 | 351 | 380 |
| ($/kg) | ( 0.44) | ( 0.82) | ( 0.84) | ( 0.78) | ( 0.84) |
| 2009 | 164 | 259 | 259 | 259 | 259 |
| ($/kg) | ( 0.36) | ( 0.57) | ( 0.57) | ( 0.57) | ( 0.57) |
| 2010 | 172 | 250 | 250 | 250 | 250 |
| ($/kg) | ( 0.38) | ( 0.55) | ( 0.55) | ( 0.55) | ( 0.55) |
| 2011 | 231 | 243 | 243 | 243 | 243 |
| ($/kg) | ( 0.51) | ( 0.54) | ( 0.54) | ( 0.54) | ( 0.54) |

Source: CMDT, 2011.

Traditional yields for the year 2009 of the main crops grown by the sample of farmers are summarized in table 2.3 and compared with aggregate yield data assembled at the district level by the Malian Ministry of Agriculture.

Table 2.3: Farm Level and Aggregate Yield Data in the Study Area

| | Maize (kg/ha) | Sorghum (kg/ha) | Millet (kg/ha) | Cotton (kg/ha) |
|---|---|---|---|---|
| Farmers' Yield 2008 | 1789 | 1376 | 1276 | 1278 |
| Aggregate data in 2008 | 2500 | 1500 | 1250 | 1134 |
| Average Aggregate data* | 1832 | 1047 | 987 | 981 |

Note: *The average aggregate data is a 10 year average data from 1998 to 2008.

From the sample of producers surveyed, traditional maize yields are by far the highest among all crops. This is also confirmed with the aggregate data. Yield increase for maize has been impressive over the past 10 years (figure 2.4) compared to cotton, sorghum and millet. The growth in maize productivity is the result of successful research efforts invested in this crop during the past decades from CIMMYT in collaboration with the national agricultural research program, IER. Surprisingly, despite the extension services provided by the CMDT, cotton yields have been stagnant and even falling in spite of the continuing use of high inputs. With declining cotton yields and increasing maize productivity farmers have been diverting cotton fertilizer from the cotton fields onto the cereals. Cotton still remains the main source of cash income for farmers. One of the reasons of farmers' constant interest in cotton is the benefits that they can get from growing cotton in the form of access to credit and fertilizer. Moreover, fertilization has a residual effect on the cereals in the crop rotation system. Also as contrasted with the grain prices volatility and harvest price collapse, cotton offers stable returns with the minimum guarantee cotton prices. Hence, greater access to fertilizer credit for the cereals and adoption of grain marketing strategies to increase return on marketing are expected to reinforce farmers' interest for cereals at the expense of cotton.

Sorghum and Millet yields are not impressive because these crops are traditionally grown without inorganic fertilizers except for the residual effects following cotton in the rotation. Thereby, the use of improved inputs on those two cereals appears to be essential for an increase in the traditional yields.

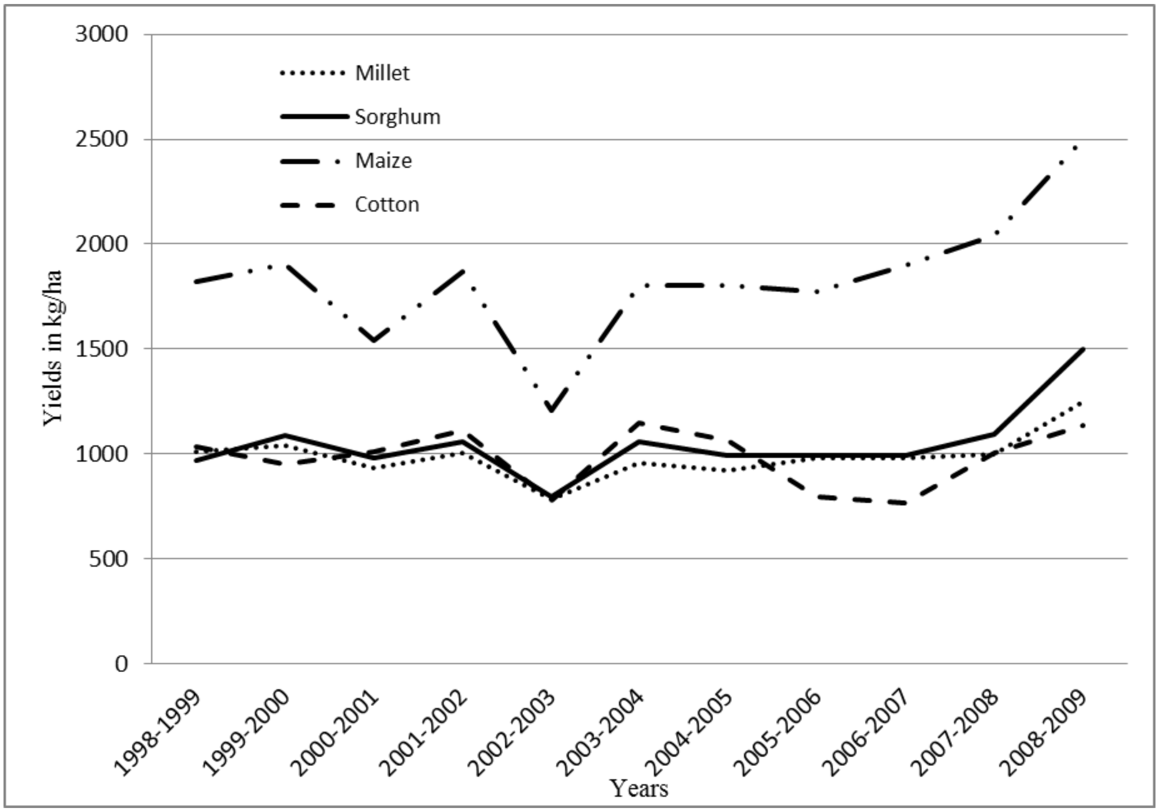


Figure 2.4: Aggregate Cotton Yields and Cereals from 1998 to 2008 in Koutiala, Mali
Source: Ministry of Agriculture, Mali

Rainfall in the area is not a severe constraint to agricultural productivity. The cercle of Koutiala is known as a high rainfall area. The average amount of rainfall from 1980 to 2009 is estimated at 800 mm (Direction Nationale de la Meteorologie 2009). In terms of annual quantity of rainfall, only 10 percent of the number of years since 1980 can be identified as poor rainfall years, while 90 percent are identified as normal and good years of production. This region encounters flooding as in the years 1994 and 2010. This is an especially serious problem for maize and sorghum as they are concentrated on the lowlands. So, excess rainfall is a factor that needs to be taken into consideration in explaining yield variability.

## 2.5 Socio-economic Characteristics of the Representative Farmers

Based on the results of the field survey of 54 farm households, the socio-economic characteristics of the representative farmer in the study area were defined. The sampling was done randomly from a population of 100 farmers who participated in the IER-INTSORMIL project for the diffusion of the improved sorghum technology.

### 2.5.1 Household Social Characteristics

In the sample of household heads surveyed, the average age of household heads is 57 years old (table 2.4). Households are extended families with on average 27 people living together among which 14 people are above 15 years old. Field labor is basically family based. On average, 10 household members work full time on the fields. In Garasso, it is very common for adult males to migrate seasonally out of the farm. In each family, an average of 2 people worked off farm seasonally in larger cities of Mali or in neighboring coastal countries (Cote d'Ivoire, Ghana and Guinea). These migrants come back to the farm to perform the farming activities required in the agricultural season. Household heads interviewed have little formal education. Most of them do not have any level of school education either in French or Arabic (table 2.4).

The main cereals consumed are by order of importance sorghum, millet and maize. But these grains are perfectly substitutable in consumption. During the interviews, farmers revealed their preference for millet and maize but the amount of maize consumed is limited by the cost of the purchased inputs for maize production. This preference for maize is consumption is expected to influence the crop allocation in response to a fertilizer subsidy. Household daily grain consumption is estimated on average at 25 kg per household or 0.93 kg per person per day.

One of the most important farming goals stated by producers is the need to meet the subsistence consumption level every year. Thereby in the model construction, this objective will be specified as a priority for farmers before maximizing their profits.

Households own a large number of cattle with an average of 20 animals per family. In fact, cattle represent a main asset for farmers. Farmers invest their cash earnings in cattle which are considered as savings. Cattle play also a key role in the farming systems. They provide the manure used as organic fertilizer on the crops and the power in animal traction farm operations. They are important sources of cash for financing the agricultural inputs for sorghum and millet and for some emergency family expenses especially at the beginning of the cropping season where farmers often are facing a liquidity constraint.

Table 2.4: Household Characteristics

| Household Characteristics | Mean |
|---|---|
| Age of the household head | 57 |
| Number of people in the household below 15 years | 13 |
| Number of people in the household between 15 years and 35 years old | 9 |
| Number of people between 35 years and 65 years old | 5 |
| Number of people above 65 years | 1 |
| Total number of people in the household | 27 |
| Number of people working full time on the field | 10 |
| Number of migrants | 2 |
| Education level of household members | 0 |
| Household grain consumption (kg) | 25 |
| Number of Cattle | 20 |

Source: Primary Survey Data
Sample: 54 farmers interviewed

### 2.5.2 Agricultural Inputs Financing

Farmers use several sources of liquidity to finance agricultural inputs such as fertilizer, seeds, agricultural equipment and hired labor used during the rainy season. These financial resources originate from livestock sales, crop sales, non-farm work, remittances, and input loans for both cotton and the improved sorghum variety (table 2.3). Eighty four percent of the input expenses come from the cotton and maize credit borrowed from the CMDT. Seven percent originate from the improved sorghum credit contracted with the producer’s cooperative working under the IER-INTSORMIL program. The remaining input expenses come by order of importance from the sales of crops (cotton, fruit trees, and grain), livestock and non-farm work. During the rainy season, few non-farm activities are performed because farmers are busy working on the fields. Producers are only able to devote time to non-farm work during the low labor demand periods of the agricultural season and during the dry season. Examples of these non-farm work are mechanic (bicycle and motorcycle repair), small food or clothing retailing activities, and blacksmith. The revenue from non-farm activities are small but represent a source of income diversification to help households to smooth consumption over time and to meet some of their expenses.

Table 2.5: Sources of Liquidity for the 2008/2009 Agricultural Campaign

| Items | Amount in F CFA | | Percentage |
|---|---|---|---|
| Cotton credit | 499,505 | ($ 1,104) | 84% |
| Sorghum credit | 41,500 | ($ 92) | 7% |
| Crops | 34,654 | ($ 77) | 6% |
| Livestock | 12,130 | ($ 27) | 2% |
| Remittances | 4,717 | ($ 10) | 1% |
| Non-farm income | 3,111 | ($ 7) | 1% |
| Other | 377 | ($ 1) | 0% |
| Total | 595,993 | ($ 1,317) | 100% |

Source: Primary Survey Data
Sample: 54 farmers interviewed
Exchange rate: 1 $ US =452.61 F CFA on April 18, 2011 at www.oanda.com

### 2.5.3 Household Income and Expenditures

There are three main periods during which income is generated and the primary expenditures occur. These are harvest (October – December), dry season (January to May) and the hungry period (June-August).

At harvest, the main source of cash comes from crop sales. Cotton sales used to be the most important cash earnings at harvest. Cotton farmers were selling back their harvest at the fixed price to the parastatal company for the repayment of the input cotton credit. After reimbursement the net revenue of farmers from cotton was returned right after harvest. However, since 2005 the cash payments to farmers have taken place much later in the year. For example in 2009, the payments were received in the month of June that is six months after harvest. This long waiting time inconveniences farmers because they usually count on these earnings to make some of their biggest expenditure requirements such as taxes, school fees, loan repayments, hired agricultural labor wages, social ceremonies expenses such as naming ceremonies, marriage, funerals, gifts to household members (table 2.6). All these customarily expenses take place around harvest time when farmers are expected to have more income. So, farmers are sometimes forced to sell grains at harvest to meet their necessary harvest expenses. The most traded grains are millet and maize because of the higher selling prices. The harvest income goal is another important objective for farmers that will be taken into consideration in the model construction.

Table 2.6: Household Expenditure Items in 2008/2009

| Expenditures Items | Amount in F CFA | Percentage |
|---|---|---|
| Food consumption | 85,869 ($ 190) | 16% |
| Animal health and feed | 85,357 ($ 189) | 16% |
| Social ceremonies | 82,704 ($ 183) | 15% |
| Health | 56,189 ($ 124) | 10% |
| Gifts to all household members | 49,367 ($ 109) | 9% |
| School fees | 48,812 ($ 108) | 9% |
| Taxes | 45,549 ($ 101) | 8% |
| Motorcycle and bicycle repair | 40,546 ($ 90) | 7% |
| Hired Labor | 22,146 ($ 49) | 4% |
| Loans | 19,056 ($ 42) | 3% |
| Others | 9,385 ($ 21) | 2% |
| Total | 544,978 ($ 1,204) | 100% |

Source: Primary Survey Data
Sample: 54 farmers interviewed
Exchange rate: 1 $ US =452.61 F CFA on April 18, 2011 at www.oanda.com

During the dry season, the reduction in the demand for labor for the agricultural activities allows farmers to be involved in non-agricultural activities to have some cash earnings. In this period of time, household expenditures include any emergency health issue, social ceremonies, livestock expenditures (feed complements and vaccinations) and the recurrent expenditures of school fees and food items. Also, at the end of the dry season, farmers start preparing the next agricultural campaign by purchasing agricultural inputs.

The hungry season or lean season is usually identified as two months right before the harvest but in this research we assume that it is lined up with the crop season for modeling purposes. During the lean season, farmers are running out of food in their storage units. This is why farmers like early maize. All family workers have to allocate their labor principally on the communal plot which is used to generate the cash income and the home food consumption. After the communal work, family members can participate in their private activities such as private plots, petty trade and agricultural gender work teams. The crop season is the time for migrant family workers to return to the farm or to send remittances to assist their families in agricultural and household expenses.

Household expenditures are spread throughout the year although the availability of cash crops at harvest gives more incentive to households to honor their debts, reward family members for their agricultural work and pay for any pressing household expenditures. The main expenses are related to food consumption, animal care and feed, and social ceremonies. The expenses for food consumption include principally expenditures for complementary items for food consumption such as meat, fish, and sauce ingredients. Purchase of grains is limited. When it occurs, it is generally during a bad crop year when quantities of grain produced are not sufficient to cover the home consumption needs for a year. On average, during a bad year the stock of grain will last only 7 months. In this case, grain purchases will be necessary during the crop season. In normal years, the stock of grain lasts almost a year, in good years it can go up to 15 months. With the adoption of high-yielding cultivars of sorghum, the level of self-sufficiency in grain consumption is expected to increase.

Household expenses vary across years. During a very good crop year, households increase their expenditures on social ceremonies specifically wedding and dowries for their children of age to get married, housing improvement, agricultural equipment, assets such as cattle and gifts to household members. The extent of gifts (grains, cash or clothing) offered to household members particularly to women depends on the state of nature of the crops as well as on the purchasing price of cotton set by the parastatal company (CMDT).

In the past, when the cotton economy was very successful, all adult household members including women were often granted clothing items and cash payments. But, nowadays with the reduced income from cotton, compensations in cash or clothing have decreased or have been completely cancelled. With the declining cotton economy, women are predominantly compensated in nature by some amounts of grains at harvest. Quantities of grains received vary according to the state of nature of the crop year. Therefore, the adoption of sorghum technologies and the government interventions in the cotton sector are expected to influence differently women's compensation after harvest.

The three critical periods of income earnings and cash expenditures discussed above will be fundamental in the development of the model as they will represent the main points where household decisions are made.

## 2.6. Summary

The study area is located in southern Mali in the district of Koutiala which is a higher rainfall area with average rainfall estimated at 800 mm. This area is an old cotton zone with depleted soils due to the long time practice of cotton and population growth. Sorghum, maize and millet are the main cereal crops cultivated in the area. In the traditional farming system, cotton and maize are cultivated intensively with the use of inorganic fertilizer whereas millet and sorghum are grown without inorganic fertilizer but benefit from the residual fertilizer effect of cotton and maize. Cotton, maize and sorghum are typically part of a crop rotation system on low-lands and better lands. Millet is generally cultivated on the poorer soils especially on the plateau and on sandy lands. The average household in the study area is composed of 27 persons, consumed 25 kg of grains per day and cultivated 15 ha of lands including 4.2 ha of cotton, 2.8 ha of millet and maize and 5 ha of sorghum.

Cotton area and productivity have been declining over time mainly driven by the falling trend of the cotton price paid to farmers and the delays in the payment by CMDT to the farmers. But with the surge in 2011 of the cotton price, farmers are expected to increase the area of cotton. Hence, the models' results will predict farmers' acreage allocation in response to the cotton price policy.

Inputs for the intensively grown crops cotton and maize are financed with the input loans from the CMDT while inputs for sorghum and millet are financed by cashing farmers 'assets of small livestock or trading crop commodities. Over the past two years, cotton and maize have benefited from the government subsidy program in which sorghum and millet were included in 2011. Fertilizer is a catalyst for yield but with increasing public expenditures, this program might not be pursued in the long run. So, the effect of the government fertilizer subsidy allocated to the different crops will be an area of investigation with the model. The income effects of the adoption of the traditional technologies will be assessed without and with the fertilizer subsidy.

The main farm household expenditures are undertaken during points in time with significant cash needs that are the end of harvest season, the dry season and the next crop season. Thus, three main periods of decision making will be defined in the model construction.

Overall, the socio-economic characteristics of the representative farmer in the study area will be used to build the modeling framework of farmers' decision making and the traditional technologies will be used to calibrate and validate the results of the model estimation. Farmers' decision making will be estimated with government intervention regarding cotton pricing policy and fertilizer subsidy program.

# CHAPTER 3: NEW SORGHUM TECHNOLOGIES AND MARKETING STRATEGIES

This chapter documents the new sorghum technologies and marketing strategies diffused in the study area to improve farmers' income. This combination of technologies has been introduced as an alternative source of income for farmers in the cotton zone given the declining cotton economy and the resulting reduction in farmers' revenues. Moreover, with the declining soil fertility and low yields of local sorghum varieties, the adoption of high-yielding cultivars and the use of moderate levels of inorganic fertilizer on sorghum are crucial to increase sorghum productivity. The chapter gives details on the higher yielding sorghum cultivar that is very responsive to the use of fertilizer and the adoption of better agronomic practices in any rainfall year.

The second innovation is represented by the improved marketing practices that allow farmers to take advantage of the price seasonality and therefore receive a higher return on marketing. The ultimate effect is expected to be an increase in the profitability of the new sorghum technology, particularly in the poor rainfall years where the seasonal price variation can double the harvest price.

## 3.1. Improved Production Technologies for Sorghum

The heavy soil types and sufficient rainfall in the Koutiala region are excellent for sorghum. This explains the large area allocated to sorghum in the traditional farming systems. So, emphasis has been put by the IER-INTSORMIL program since 2005 on the diffusion of new technologies of sorghum in this region. The technological package for sorghum is a combination of higher yielding varieties, soil management technologies, improved agronomic practices such as thinning and the use of moderate amounts of inorganic fertilizers. The technologies are expected to alleviate the constraints of soil fertility and relatively poor traditional crop yields. So, farmers will adopt the new technologies if the innovations generate substantially higher yield gains over the traditional varieties. To do this the first prerequisite is to increase soil fertility.

### 3.1.1 Ridging and Tied Ridging

A large percentage of lands in the study area are degraded lands with low water retention capacity. Thus, ridging is perceived as a soil management technology important to increase soil moisture which leads to higher returns from the fertilization. It is used as a land preparation technique performed before planting after the first rainfall or during the weeding activities. Conventional ridge cropping has become a main component of the traditional farming systems on the most degraded lands. The decreasing land quality pushes farmers to perform this practice despite the fact that the returns are low when performed on degraded lands. The economic return is much higher when the technology is applied before soil degradation (Sanders et al. 1996).

Tied ridging is a technology improvement over the traditional ridges. It consists of ridging the soil and cross tying the ridges to reduce the run-off of water from the soil. Hence, tied ridging has the advantage to decrease the loss of water and mineral elements from the soil and to conserve water in the soil longer. It therefore controls for erosion and increases the soil moisture necessary for good crop germination. This practice leads to substantial crop yield gains over the traditional simple ridges and does not require significantly higher labor contribution. Sanders et al. (1996) reported that the adoption of tied ridging increases yields by approximately 50 percent and farm income by 12 percent.

### 3.1.2. Inorganic Fertilizer

Soil deficiencies in Nitrogen (N) and Phosphorus (P) are identified as major constraints for the production of sorghum. Inorganic fertilizer is thus an essential input for crop production because it enhances crop productivity through intensification rather than area extension. Application of fertilizer has been conducted over thirty years in the study area but application was on cotton and maize.

Extensive availability of inorganic fertilizer for all crops is constrained by marketing infrastructures, credit and governmental support. Many farmers lack cash to be able to purchase significant amounts of inorganic fertilizer. Thus, to facilitate adoption of fertilizer and improve sorghum yields, the IER-INTSORMIL project has procured moderate amounts of inorganic fertilizers for farmers providing input credit. Farmers involved in the program reimburse fertilizer in grains to the farmers' association thereby creating a revolving fund to continue fertilizer purchase over time.

The recommended fertilizer levels are 100 kg/ha of NPK and 50 kg/ha of Urea. The nutrient content of the NPK is 15-15-15. More recently, farmers have switched to a lower cost package of inorganic fertilizer represented by the di-Ammonium Phosphate (DAP). The inorganic formula is 18-26-0 and the principal focus of fertilization is on Nitrogen and Phosphorus because Potassium (K) is generally sufficient.

### 3.1.3. High Yielding Cultivars

The gains in production due to adoption of soil management practices and inorganic fertilizer need to be supplemented with high-yielding seed varieties responsive to fertilizer. Several sorghum cultivars have been introduced over time to improve the response to the local agronomic conditions and produce higher yields. Currently, the new variety diffused is a Caudatum which is an intermediate cycle variety as opposed to the local varieties that are long cycle varieties. The local name of the improved variety is Grinkan.

The improved Grinkan variety is high yielding, very responsive to the use of inorganic fertilizer and more tolerant to Striga infestation and some plant diseases compared to the traditional cultivars. In addition, according to some farmers, the improved sorghum cultivar is more resistant to flooding damage compared to the local varieties. Average crop yield in normal years is about 1.4 tons to 1.9 tons with the best farmers reaching 2.5 tons to 3 tons per hectare with the combination of soil management technologies, use of inorganic fertilizer and rigorous implementation of agronomic practices at specific periods of the plant cycle (Coulibaly 2010). The yield gains over the traditional varieties are considerable and are 40 percent higher for the average farmer during a normal rainfall year.

Nevertheless the net returns on production of the improved sorghum for the average farmer are almost similar to the one of the traditional varieties for the crop year 2008/2009 when the grains are sold at the harvest price of 80 F C FA/kg (table 3.1).

A first implication of this latter result is that for very high input costs such as those of the year 2008/2009, the average farmer might be indifferent between adopting and not adopting the improved sorghum while the most efficient farmer will have a stronger incentive to adopt. To enhance return on adoption, it is necessary to increase yield through a rigorous implementation of the agronomic practices or to lower the production costs. Hence, we observe that in 2011, there is a very high return on technology adoption with the subsidized cost of fertilizer (table 3.1). This outcome suggests that at affordable fertilizer costs, the average farmer will have a higher willingness to adopt the improved sorghum and to substitute more for the local varieties.

Table 3.1: Returns for the Traditional Sorghum and the Improved Sorghum Cultivar. Crop Year 2008 and Estimations for 2011

| | Traditional Cultivar Crop Year 2008 | Improved Cultivar Crop Year 2008 | Improved Cultivar Crop Year 2011 |
|---|---|---|---|
| Inputs Items | | | |
| Seed (F CFA/ha) | 4,000 | 1,200 | 1,200 |
| NPK (F CFA/ha) | 0 | 36,000 | 25,000 |
| Urea (F CFA/ha) | 0 | 19,000 | 12,500 |
| Total Inputs Cost[7] (F CFA/ha) | 4,000 | 56,200 | 38,700 |
| Yield (kg/ha) | 1,154 | 1,642 | 1,642 |
| Harv.Price* (F CFA/kg) | 80 | 80 | 80 |
| Total Revenue1 (F CFA) | 92,320 | 131,360 | 131,360 |
| Net Return1 (F CFA) | 88,320 | 75,160 | 92,660 |
| Rec. Price **(FCFA/kg) | | 115 | 115 |
| Total Revenue2 (F CFA) | | 188,830 | 188,830 |
| Net Return2 (F CFA) | | 132,630 | 150,130 |

Note: Harv.Price*= This is the expected harvest price collected in the regional market of Koutiala (Mali) in 2008
Total revenue1 and Netreturn1 are those obtained with the harvest price of 80 F CFA/kg ($/kg 0.18)
Rec.Price**= This is the expected price during the price recovery period collected in the regional market of Koutiala (Mali) in 2008
Total Revenue2 and Net Return2 are those obtained with the recovery price of 115 F CFA/kg ($/kg 0.25)
Exchange rate: 1 $ US =452.61 F CFA on April 18, 2011 at www.oanda.com

A second implication of the results reported in table 3.1, is that selling the grains at harvest, does not lead to significant return on adoption of the improved sorghum technology because of the harvest price collapse. But, when farmers are able to sell the improved sorghum in the price recovery period, return on technology are substantially higher (see table 3.1). So, in addition to increasing yields or reducing costs of fertilizer, farmers must be able to sell sorghum at higher market prices to increase profitability of

[7] We didn’t include labor costs in the total input costs as most the labor used is family labor. There would be some additional costs including increased labor from higher plant and weed density resulting from more fertilization. Also more labor woluld be required by the new operations especially thinning which farmers do not normally do and the split application of fertilizers.

the new technology and the return on adoption. With increased sorghum production following the adoption of the higher yielding cultivar, farmers in the farmers' association have the opportunity to store the excess grains above consumption and sell when prices are higher in the market.

## 3.2 Grain Marketing Strategy

The development of marketing strategies contributes to increase the profitability of the improved technologies. Higher yields reduce costs of output. Farmers are more willing to adopt agricultural technologies when those innovations are able to increase profitability. Unfortunately, technology introduction of staples is constrained by three types of price collapses.

Prices collapse during years of good or even normal rainfall because of the price inelasticity of demand. Once households with sufficient income to buy cereals have enough, there are few alternative markets to keep prices from collapsing. In the regional market of Koutiala, prices of sorghum as well as other grains collapsed during the good rainfall years of 1999, 2003 and 2006 as opposed to the years 2001 and 2002 which were poor rainfall years (table 3.2). The between year price collapse in sorghum as well as in other grains introduce more riskiness in grain prices as revealed by the larger value of the coefficient of the standard deviation compared to cotton (table 3.2) for which a minimum guaranteed price is fixed yearly at the beginning of the cropping season by the government. The lower price variability of cotton is an attraction but the previous other advantage of obtaining cash near the harvest time has been reduced in recent years by the tardiness of CMDT in paying farmers. Moreover, real cotton prices have been falling for most of the 21st Century until 2011.

Table 3.2: Real Producer and Consumer Prices, and Coefficients of Variation from 1998 to 2008

| Years | Millet Prices (F CFA/kg) | | Sorghum Prices (F CFA/kg) | | Maize Prices (F CFA/kg) | | Cotton Prices (FCFA/kg) |
|---|---|---|---|---|---|---|---|
| | PP* | PC* | PP | PC | PP | PC | PP |
| 1998/1999 | 135 | 181 | 129 | 168 | 106 | 147 | 262 |
| 1999/2000 | 75 | 112 | 72 | 111 | 61 | 100 | 214 |
| 2000/2001 | 121 | 166 | 107 | 144 | 101 | 162 | 224 |
| 2001/2002 | 174 | 221 | 170 | 212 | 144 | 187 | 252 |
| 2002/2003 | 168 | 217 | 149 | 190 | 119 | 166 | 235 |
| 2003/2004 | 77 | 113 | 63 | 98 | 57 | 85 | 255 |
| 2004/2005 | 153 | 189 | 144 | 173 | 127 | 159 | 255 |
| 2005/2006 | 124 | 151 | 103 | 124 | 89 | 110 | 188 |
| 2006/2007 | 87 | 102 | 79 | 95 | 72 | 86 | 184 |
| 2007/2008 | 107 | 123 | 97 | 114 | 104 | 120 | 174 |
| 2008/2009 | 126 | 145 | 110 | 127 | 110 | 128 | 200 |
| Mean | 122 | 156 | 111 | 141 | 99 | 132 | 222 |
| ($/kg) | (0.27) | (0.34) | (0.25) | (0.31) | (0.22) | (0.29) | (0.49) |
| Standard dev | 34 | 42 | 34 | 39 | 27 | 35 | 32 |
| Coef of var | 0.28 | 0.27 | 0.30 | 0.28 | 0.28 | 0.26 | 0.14 |

Note: PP*=Producer Prices, PC*= Consumer Prices. Prices have been deflated by using the year 2008 as the base year. Exchange rate: 1 $ US =452.61 F CFA on April 18, 2011 at www.oanda.com.
Standard dev. stands for standard deviation; Coef. of var .stands for coefficient of variation
Source: Author own Calculation from Aggregate Data and Index of Inflation from 1998 to 2008.

In addition to the between year price variation and collapse, there is a within year price variability with prices falling at harvest because most farmers sell their crops to finance the necessary harvest time expenditures. These expenditures are a series of traditional requirements including school fees, local taxes, paying workers for agricultural activities during the last crop season, financing younger males to migrate to cities for seasonal employment, and traditional ceremonies such as marriages and naming ceremonies. The price collapse results from most farmers feeling the necessity to have funds at harvest.

Then prices start increasing after this collapse. From January (harvest season) to May (recovery price season) prices increase on average by 27 percent (table 3.3). From May to September (lean season) there is an average smaller price increase in the market. This results because the public sector often intervenes in this second season to keep prices from increasing further. Moreover, merchants with larger stocks start unloading with larger quantities in this second period. Thus the greatest increase in the returns to storage has historically been selling in the recovery period. However, if the government does not intervene, there is substantial potential to sell later in the lean period especially in poor rainfall years.

Table 3.3: Sorghum Production (Kg/ha) and Producer Prices (F CFA/kg) across Marketing Periods

| Year | Production (kg/ha) | Period 1 Prices | Period 2 Prices | Period 3 Prices | Percentage Change | Percentage Change |
|---|---|---|---|---|---|---|
| | | Harvest Season | Recovery Period | Hungry Season | Period 1 to 2 | Period 2 to 3 |
| 1998 | 971 | 119 | 135 | 124 | 14% | -9% |
| 1999 | 1090 | 80 | 73 | 65 | -9% | -11% |
| 2000 | 978 | 65 | 117 | 153 | 79% | 31% |
| 2001 | 1056 | 114 | 185 | 202 | 62% | 9% |
| 2002 | 798 | 157 | 157 | 115 | 0% | -27% |
| 2003 | 1059 | 56 | 65 | 72 | 15% | 11% |
| 2004 | 994 | 90 | 158 | 196 | 76% | 24% |
| 2005 | 989 | 96 | 108 | 103 | 13% | -5% |
| 2006 | 991 | 69 | 73 | 93 | 7% | 27% |
| 2007 | 1095 | 82 | 90 | 120 | 9% | 34% |
| 2008 | 1500 | 80 | 109 | 138 | 37% | 26% |
| Average | 1047 | 92 ($/kg0.20) | 115 ($/kg0.25) | 126 ($/kg 0.28) | 27% | 10% |

Note: Exchange rate: 1 $ US =452.61 F CFA on April 18, 2011 at www.oanda.com.
Prices have been deflated by using the year 2008 as the base year.
Source: Author own Calculation from Aggregate Data and Index of Inflation from 1998 to 2008.

The third type of price collapse occurs during adverse years for crop production when the government often intervenes to drive down prices paid by consumers usually after they have increased substantially. For example during the poor crop year of 2002 the Malian government imported grains from Ivory Coast and Burkina Faso and released grains from its warehouses. Though there is a public stock policy, government release of stocks is not very common due to their financial limitation to generate and hold substantial stocks of grains. Import of grains from neighboring countries is a more common policy. In figure 3.1, we notice that during the crop year 2002, grain prices started falling by June (the lean season). In the last decade donors have been increasingly reluctant to help governments drive down the prices and thereby reduce incentives in agriculture.

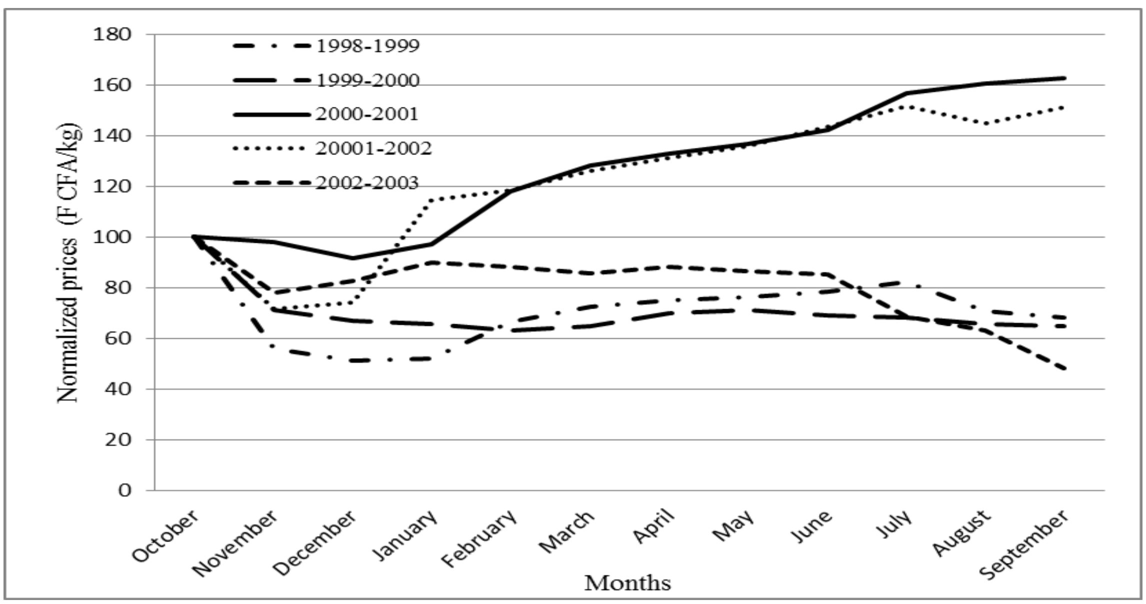


Figure 3.1: Normalized Producer Prices for Sorghum from 1998 to 2002
Source: National Marketing Watch (OMA/Mali)

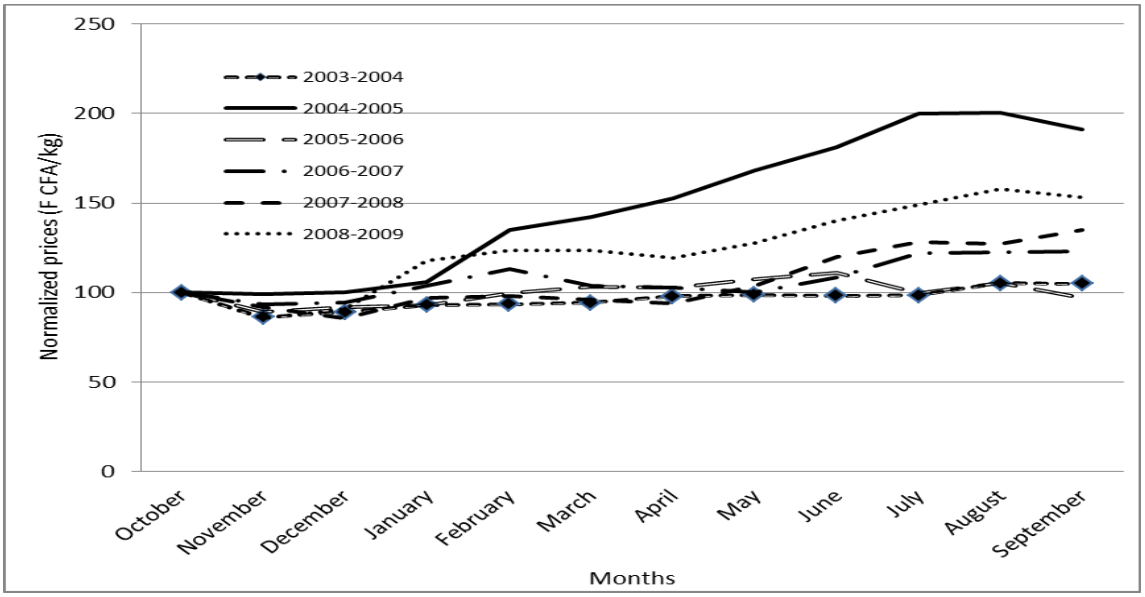


Figure 3.2: Normalized Producer Prices for Sorghum from 2003 to 2008
Source: National Marketing Watch (OMA/Mali)

Given the seasonality in prices developed above and depicted in figures 3.1 and 3.2, new marketing strategies need to be implemented to assist farmers in dealing with at least the first two types of price collapses. Specifically, the model is concerned with the storage and the higher prices from selling later in the year. But other strategies including increasing farmers' negotiation power through learning by doing process are also important since they have potential to increase return on marketing.[8]

### 3.2.1 Grain Storage and Late Sales

Grain storage at harvest and late sales within the year enable farmers to avoid the harvest price collapse and thereby take advantage of the price increase later in the year.

[8] To respond to the price inelasticity problem new market development for the cereals is the on-going strategy of the Production-Marketing project of INTSORMIL. As the intensive poultry sector continues to rapidly expand, sorghum should be able to compete with maize but this was not included in the modeling.

farmers' cooperatives buy grains from their members at harvest and store these cereals in storage facilities until prices recover from their harvest collapse. But very poor farmers with a lack of alternative financial resources for the harvest expenditures are often unable to forgo their harvest income by participating in this collective grain storage store their grains. Nevertheless, by obtaining access to the banks for the input purchases or inventory holdings, famers have the opportunity to get credit for consumption while storing their grains up to the period of price recovery.

### 3.2.2 Increasing Producer Bargaining Power

The increase in farmers' bargaining power is an important strategy to capture higher marketing margins. Farmers are encouraged to market their sorghum grains through the producers' associations in order to increase their bargaining power and take advantage of the economies of scale. By being involved in associations, producers have the opportunity to buy inputs and sell sorghum in larger quantities to wholesalers instead of dealing with individual intermediaries who can take advantage of their lack of knowledge of market prices and thus capture large benefit in the supply chain. Hence, farmers' collective action enables them to benefit from storage and from a higher price by selling in bulk quantity. The producers association can also invest more in market information than the individual farmer.

## 3.3. Summary

The new sorghum technologies diffused in the study area consist of an improved sorghum cultivar, use of moderate levels of fertilizer and the implementation of better agronomic practices. These new technologies lead to higher yields and expected profits than with the traditional sorghum. Thus, farmers should develop more interest in growing the new sorghum cultivar if they have access to the new technology package. Higher profitability of the new sorghum technology is also expected to be achieved by the adoption of marketing strategies based on storage and late sales, especially in the price recovery period.

The higher yielding cultivar associated to the use of moderate levels of fertilizer for the improved cultivar and the adoption of efficient marketing strategies will be introduced in the model to assess the impact on farmers' decision making and income. The results will be compared to the base case scenarios where no improved agricultural technologies for sorghum are used. Under the adoption of improved sorghum technology, the income effect of the cotton pricing policy and fertilizer subsidy will be estimated and compared with the base case scenario characterized by the traditional technologies.

# CHAPTER 4: METHODOLOGY AND DATA

In this chapter, we will develop a model to represent farmers' decision making process in the study area. The representative farm household in the study region is assumed to maximize the expected ending wealth subject to some resource constraints such as labor, land and other agricultural inputs. Based on field research and interviews conducted in the study region and on empirical research performed in several other sub-Saharan countries, farmers take their decisions in order to cope with risk. The previous chapters showed that farmers face many sources of risk in agriculture and grain marketing including variability in rainfall, crop yields and commodity prices. These risk factors influence farmers' production, consumption and marketing decisions. Farmers' decisions are made sequentially across marketing periods based on the outcomes of yields and prices randomness. The planning period in which farmers make their decisions starts at the beginning of the planting season in June up to the end of the lean season in September.

After providing a justification for the choice of the sequential stochastic farm modeling approach, this chapter discusses in a following section the stochastic environment in which farmers make their decisions. Next the decisions variables included in the model are described. Then, the empirical model is presented and in a last section the data used for the model estimation are provided.

## 4.1. Justification of the Model

Several methods have been described in the literature to measure the income effects of agricultural technologies and to evaluate farmers' decision making in an uncertain environment. Uncertainties are related to some stochastic events including rainfall distribution, input and output prices which affect famers' production decisions and marketing strategies.

The most common theory used to analyze farmers' decisions under risk is the expected utility theory. This theory assumes that the decision maker chooses between risky or uncertain plans by comparing their expected utility and selecting the one that yields to the highest utility (Hazell and Norton 1986). Depending on the decision maker's preference or utility function, diverse types of models can be used to assess farmers' decision making with the expected utility theory. Mean-Variance models (EV) are used when the utility function reflects normally distributed returns. These models involve mathematical programming and can be applied to identify the set of efficient portfolios with the smallest variance from the mean. An alternative to the Mean-Variance model is the MOTAD model (Hazell and Norton 1986). This model solves for an efficient portfolio set by minimizing the absolute deviation of a portfolio from the mean portfolio. Implementation of the MOTAD is based on linear programming. Adesina, Abbott and Sanders (1988) used a MOTAD model to estimate the impact of agricultural technologies in Niger. Their results show that adoption of fertilizer depends on farmers' level of risk aversion. Highly risk averse farmers adopt fertilizer on limited crop area as opposed to less risk averse producers.

Other programming techniques incorporating risk include safety-first models and lexicographic utility functions. Safety first models are appropriate in highly risky environment. It ensures that the farmer maximizes his income after securing his subsistence needs. This model has been used to explain producers' behavior related to the levels of fertilizer adoption (Bell 1972), land allocation to food and cash crops (Carter and Wiebe 1990) or area of land allocated to improved and traditional technologies (Smale, Just, and Leathers 1994). Lexicographic utility functions assume that farmers cope with risk by making their decisions to satisfy ordered goals. While in safety first models farmers have one main subsistence goal to achieve before maximizing their income, lexicographic utility functions allow for more than one goal to be secured. Hence, empirical application studies on agricultural technology adoption in developing countries, by Abdoulaye and Sanders (2006), Baquedano et al. (2010) identified a subsistence objective and a harvest income requirement as principal goals farmers need to satisfy prior to maximizing their profit.

The models described above were extensively used to capture stochastic events in agricultural production and to estimate the impact of agricultural technologies on producers' income. However, these models are static and assume that all decisions are made at one point in time. This assumption places some restrictions on the use of these modeling techniques because they do not permit farmers to make adaptive production and marketing decisions based on new information received over time. Yet, farmer interviews in Mali revealed that producers make decisions at several points in time in order to cope with production and marketing uncertainties. It is therefore necessary to use a modeling framework that takes into account farmers' ability to adjust their decisions over time. Also, there is a growing recognition of the importance of sequential decision making as farmers 'strategies in coping with uncertainty (Fafchamps 1993, Dorward 1996).

Discrete Stochastic Programming (DSP) model appears to be very appropriate to analyze sequential farmers' decision making under uncertainty. This model has the advantage to handle conditional strategies which allows future decisions to be influenced by past decisions (Preckel 2008). Moreover, in addition to handle randomness in the objective function, this model accommodates also randomness in the constraint parameters or the right hand side of the constraints.

Application of DSP has been limited in empirical research. Empirical agricultural studies with discrete stochastic programming models have started with the work of Cocks (1968). He developed a multistage farming problem in which labor requirement and gross margin are stochastic decision variables with discrete probability distribution. Rae (1971) further discussed the capability of DSP in solving problems with sequential decisions under uncertainty by applying this model to a farm management problem. Although much attention has been devoted to the application of this model in developed countries, some authors have used this model to analyze agricultural issues in developing nations. Adesina and Sanders (1991) and Shapiro et al. (1993) used this model to show that peasant farmers in Niger have the ability to adapt cropping and resource management strategies to the rainfall pattern. Lopeiz-Pereira et al. (1994) determined the income effect of soil conservation strategies and seed-fertilizer technologies in Ecuador by using a discrete stochastic model. More recently, Maatman et al. (2002) applied a sequential programming approach to describe farmers' decision making in Burkina Faso regarding grain consumption, sales, storage, and purchases throughout the growing and post-harvest seasons.

A common feature across the studies mentioned above is that rainfall and/or yields were the only random variables influencing farmers 'decisions. Their methodologies did not allow for randomness in prices. Yet, variability of harvest and post-harvest prices are equally important sources of uncertainty that may influence farmers 'decision making. To fill the gap, this study takes into account price uncertainties as well as yield variability in analyzing farmers' production, inventory and marketing decisions over time. Thus, to the best of our knowledge, this research is the first empirical study in sub-Saharan Africa that evaluates the impact of new agricultural technologies and marketing strategies within a context of stochastic crop yields and prices.

The implementation of a discrete stochastic programming model requires several steps as follows: the specification of the random variables and construction of the probability distribution, the identification of the decision variables and constraints within each stage and the definition of the objective function for the planning horizon.

## 4.2. Stochastic Environment

The stochastic environment discusses variation of yield and prices as well as defines the probability distribution of the random variables.

### 4.2.1 Random Variables

The specification of the DSP stochastic events requires first the definition of the random variables included in the model. The random variables of interest are crop yields and prices. Yields for the traditional crops concern cotton, sorghum, maize and millet.

The improved crop yield includes only the new sorghum cultivar. Crop yields are chosen as random variables instead of rainfall because rainfall does not explain all variability in yields. Yields are determined by rainfall since agriculture in Mali is mainly rain fed. But other factors such as temperature, soil fertility and agronomic practices influence the yield outcome for a given crop year. So, by choosing yields as random variables, we take into consideration all possible factors that have an impact on yields. Since the study area is known as a high rainfall area, flooding is sometimes encountered and can be as detrimental to the crop yield as drought is. Figures A.1 to A.3 in appendix A show the quadratic relationship between yields and rainfall. Yields increase with rainfall but are negatively affected by excess rainfall. Yield of cotton in addition to rainfall is also predetermined by the announced cotton price at the beginning of the planting season (see table A.1 in appendix A). So, cotton prices are exogenous non- random variables fixed by the CMDT parastatal company

Grain prices are considered as the second set of random variables and influence the marketing decisions. Marketing decisions are taken at points in time with substantial cash needs. These are the beginning of the cropping season, the harvest season and the lean season. At the beginning of the planting season, farmers need money to purchase agricultural inputs. At harvest, they need cash to compensate hired labor employed during the cropping season or for some pressing household expenditures. During the lean season, they need some financial resources to purchase grains when their stocks are depleted. Harvest prices are influenced by yield outcomes. We used Ordinary Least Square (OLS) regressions and aggregate data from the crop year 1998/1999 to 2007/2008 to show the dependence between yearly harvest prices and yields for the grains sorghum, maize and millet (equation 4.1). The results are reported in table 4.1.

$$P_{it1} = \beta_0 + \beta_1 y_{it1} + \varepsilon_{it1} \tag{4.1}$$

$P_{it1}$ = Harvest prices for grain crop *i* in year *t*

$y_{it1}$ = Harvest yield for grain crop *i* in year *t*

$\beta_0 ; \beta_1$ = Constant term and coefficient for the yield variable

$\varepsilon_{it1}$ = Error term for the equation of grain crop *i* in year *t*

Results of these regressions reported in table 4.1 indicate a significant relationship between grain yields and harvest prices, especially for sorghum and maize. The small data set might explain the low values of the $R^2$. Other explanations may first be lying in the argument of the higher rainfall area characterizing the south of the country, which is our study area. Large amount of rainfall in this part of the country might certainly reduce much of the yield variability over the years which could lead to a low significance level of the regression model. This might not be the case in the northern low rainfall areas of Mali where we should expect to see more variability in yields. Secondly, the relatively weak correlation between prices and aggregate production is an indication that other factors such as grain trade flows in the Malian economy and to a lesser extent government carry-over stock exert a significant influence in explaining the variations in aggregate producer prices.

Table 4.1: Relationship between Harvest Crop Prices and Own Crop Yields and from 1998 to 2007

| Harvest Prices | Intercept | Yield Coefficient | Adjusted $R^2$ | F | Standard deviation of residuals |
|---|---|---|---|---|---|
| Sorghum | 336.94***<br>(58.88) | -0.24**<br>(0.09) | 0.40 | 7.24** | 21.93 |
| Millet | 305.62**<br>(132.57) | -0.20<br>(0.14) | 0.12 | 2.18 | 27.84 |
| Maize | 178.20***<br>(52.04) | -0.05*<br>(0.03) | 0.22 | 3.47* | 19.33 |

Note: N=10 and standard error of the coefficients are reported in parentheses
***= significance at 1 % level of confidence, **= significance at 5 % level of confidence and *=significance at 10% level of confidence

To have a good understanding of the relationship between prices in the different marketing periods several OLS regressions were performed. The goal of these regressions is to analyze price seasonality. There is interdependence between prices at different marketing periods and we want to know how well prices in a given marketing period are impacted by prices in earlier marketing stages. These analyses are essential for farmers' decision making because farmers' marketing strategy is determined by their information about current prices but also by past random events.

For this aim, three sets of OLS regressions have been performed (equation 4.2). In the first set of regressions, prices for sorghum, millet and maize in the recovery season have been regressed against own harvest prices. A weighted average is used for harvest prices to reflect adequately the timing of the marketing decisions. Based on empirical observations, the largest part of the grains sold at harvest occurs in the month of December. So, upon field reports and technicians advice, we attributed a weight of 20 percent to the grain prices for the month of October and November and a weight of 60 percent for the month of December. Prices in the recovery period are represented by the average price of April and May. Farmers' objective is to sell their stock of grains during those months as prices experience sizable increase. In the second set of regressions, prices in the lean season are estimated as a function of harvest prices and prices in the recovery period for each of the commodities mentioned previously. Here, prices in the lean season are characterized by the average price of August and September which are the months with the highest prices for the hungry season.

Overall, we performed OLS regressions on grain prices to reflect their conditional nature with time series price observations across 10 years.

$$P_{itp} = \beta_0 + \beta_1 P_{itp-1} + \varepsilon_{itp} \tag{4.2}$$

$P_{itp} =$ Prices for grain crop *i* in year *t* and marketing period *p*

$P_{itp-1} =$ lag price for grain crop *i* in year *t*

$\beta_0 ; \beta_1 =$ Constant term and coefficient for the lag price variable

$\varepsilon_{itp} =$ Error term for the equation of grain crop *i* in year *t* and marketing period *p* assumed to be normally distributed with mean zero and constant variance.

The results of the set of regression equations between harvest prices and prices in the recovery period show high values of $R^2$ meaning that harvest prices predict very well variation in the post-harvest prices of April and May (table 4.2). Knowing harvest market prices help farmers to predict prices in the post-harvest season.

Table 4.2: Estimation of the Relationship between Crop Harvest Prices and Own Prices in the Price Recovery Period

| April-May Prices | Intercept | Harvest Prices | $R^2$ | F | Standard deviation of residuals |
|---|---|---|---|---|---|
| Sorghum | 24.38 | 0.99** | 0.46 | 8.54** | 28.96 |
| | (32.85) | (0.34) | | | |
| Millet | 28.53 | 0.88** | 0.36 | 6.14** | 31.42 |
| | (40.40) | (0.35) | | | |
| Maize | 21.34 | 1.03** | 0.43 | 7.69** | 24.23 |
| | (31.42) | (0.37) | | | |

Note: N=10 and standard error of the coefficients are reported in parentheses
***= significance at 1 % level of confidence, **= significance at 5 % level of confidence and *=significance at 10 % level of confidence

Results of the set of regressions between prices in the lean season and prices in the two preceding periods (table 4.3) show a very strong and significant dependence among prices. Prices in the lean season are well predicted by prices in the recovery and harvest periods

Table 4.3: Estimation of the Relationship between Crop Prices in the Hungry Season and Own Prices in the Recovery and Harvest Periods.

| Aug-Sept Prices | Intercept | April-May Prices | October-December Prices | $R^2$ | F | Standard deviation of residuals |
|---|---|---|---|---|---|---|
| Sorghum | 48.50*** (13.11) | 1.52*** (0.14) | -1.08*** (0.19) | 0.94 | 66.93*** | 10.45 |
| Millet | 42.24** (14.26) | 1.43*** (0.12) | -0.77*** (0.16) | 0.96 | 77.36*** | 10.06 |
| Maize | 50.78* (22.04) | 1.29*** (0.24) | -0.99** (0.35) | 0.81 | 15.10*** | 15.47 |

Note: N=10 and standard error of the coefficients are reported in parentheses.
***= significance at 1 % level of confidence, **= significance at 5 % level of confidence and *=significance at 10 % level of confidence

### 4.2.2. Probability Distribution of the Random Variables

Using the Gaussian Quadrature approach (see appendix B), 17 states of nature for yields were defined with the sum of the probability of occurrence of the 17 events equal to 1. Among those 17 states of nature, one event happens at harvest. Then, from the realized yield outcome, harvest prices are determined. At the end of the recovery season the states of nature of second period prices are realized conditional on harvest prices and yields. Next, prices fluctuate during the lean season and at the end of this period we have realization of the lean season price state of nature conditional on the outcomes of prices and yields in the preceding periods.

The values of the error terms in the grain price regression equation for each marketing period (see equation 4.2) were used to construct the probability distribution of prices in each marketing period. Observations for prices are only available for 10 years so an empirical distribution was used to define the states of nature and their associated probabilities. Thus, 10 states of nature were defined for prices in each marketing period with a probability of occurrence of one event equals to 1/10.

At the end of the year, the total number of states of nature is the product of the events that were obtained in each decision period. This product is equal to 17,000 that is

17x10x10x10. The probability of the end period states of nature is also obtained by multiplying the probabilities of the outcomes that unfold in each time period. As we can notice, the size of the DSP increases exponentially with the number of stages and states of nature but the modeling of number of states of nature achieved is feasible with current computer capacity.

## 4.3 Decision Variables

The decision variables are best described using the decision tree that summarized the sequential and stochastic process (figure 4.1). Circles in the decision tree represent realization of the random events while squares depict points in time where the decisions are made conditional on the occurrence of the states of nature. It is assumed that decisions are made at the beginning of each stage. Three stages are identified in the decision tree.

The first stage in the decision tree describes the agricultural season. This initial stage extends from the beginning of the agricultural season of year 1 (June) up to the harvest of year 1 (December). At the start of the pre-harvest period, decisions regarding land allocation across crops (millet, sorghum, maize and cotton), inputs used such as fertilizer application, amount of grains to trade in the market and the transfer of stock of grains to the next stage are taken. All these decisions are made with subjective probabilistic knowledge of the states of nature of yields. These decisions are constrained by resources availability including land, non-labor inputs, labor, cash or credit availability. Under the traditional technologies, farmers finance their inputs for grain crops with cash originating from grain sales, cotton revenue from the previous harvest as well as livestock sales. Cotton inputs and fertilizer for maize are purchased with the credit received from the parastatal cotton company. At the beginning of the growing season, the yearly price of cotton at which the parastatal company will buy cotton from framers is announced. This price is expected to influence farmers' land allocation decisions and the use of purchased inputs. At the end of the agricultural season, the outcomes of the randomness of crop yields and grain prices are known and represented respectively by $Y_{h1}$ and $P_{h1}$ on the decision tree. The probabilities of occurrence of these two events are respectively $a_1$ and $b_1$.

Stage 2 is the price recovery period. It starts at the end of the first harvest (January) and goes up to the beginning of the next growing season (June). At the beginning of stage 2, farmers have full knowledge of the realization of the random yields and the prevailing crop prices associated with crop yields but they have only subjective probability estimates of the post-harvest prices which will occur later in the year. The outcome of yields and prices in stage 1 influenced the decisions made in stage 2. Thus, conditional upon the yield and price outcomes and their conditional knowledge regarding the future distributions, farmers decide on the amount of crop to sell immediately at harvest, buy, store for consumption or sell later in the year. Hence, at harvest, farmers face several marketing decisions. They sell grains at harvest to satisfy some necessary harvest expenditures. Those expenditures at harvest include payment of hired labor, school fees, any eventual health expenses or social ceremonies. Also, during a good state of nature, farmers are able to store grains above domestic consumption and sell later in the year. Sorghum grain, especially the improved variety is usually stored collectively in the cooperative storage house and sold at the end of the price recovery period. At the end of stage 2, one outcome of the price states of nature in the recovery period occurs that is $P_{r1}$ conditional on the preceding harvest price $P_{h1}$. This realization occurs with a probability $c_1$.

Stage 3 portrays the lean season. This stage starts at the beginning of the second growing season (June) and ends at the second harvest (December). At the beginning of stage 3, farmers have full knowledge of the post-harvest grain prices that prevailed in the recovery period. Recovery prices have been determined conditionally on harvest prices. Thus, the set of activities selected at the start of the hungry season takes into account realization of prices during the recovery period and harvest season. The decisions made by farmers include grain sales, grain purchases and home consumption. At the end of stage 3, the outcome of price uncertainty in the hungry season is known and identified in the decision tree as $P_{hu1}$ with probability $d_1$.

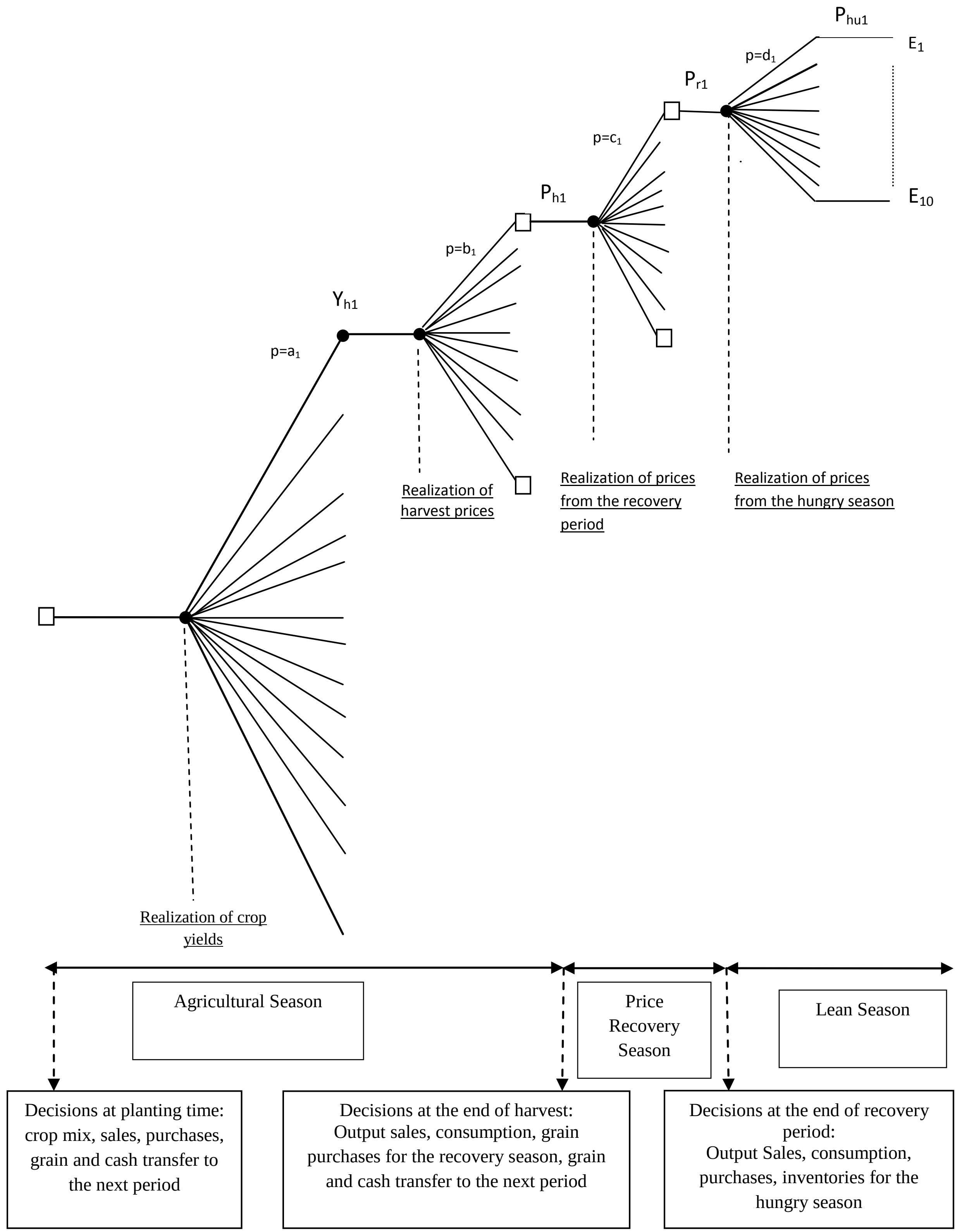


Figure 4.1: Decision Tree for the Discrete Stochastic Model

## 4.4 Empirical Model

The empirical formulation of the model requires specification of material and cash balances in each time period. Then, the expected wealth at the end of the planning horizon is maximized.

### 4.4.1. Material Balances

Material Balance at First Planting up to First Harvest

$$C_{1k} + S_{1k} + I_{1k} \leq Q_{1k} + B_{1k} \tag{4.3}$$

In equation (4.3), the starting inventory of output $k$ ($Q_{1k}$) is used for consumption ($C_{1k}$), sales ($S_{1k}$) and the remainder ($I_{1k}$) is kept in the form of inventory stock. This constraint allows cereals to be purchased ($B_{1k}$) in the event that the starting stock is not enough to meet the household grain consumption needs. Minimum subsistence requirements for the grains are defined in this period as well as in the subsequent periods as households need to guarantee a food security level before satisfying any other objective.

Material Balance from First Harvest to the Hungry Season

$$C_{2ks} + S_{2ks} + I_{2ks} \leq I_{1k} + \sum_j b_{kjs} y_j + B_{2ks} \tag{4.4}$$

Equation (4.4) specifies that consumption ($C_{2ks}$), sales ($S_{2ks}$) and inventory of output $k$ for a given state of nature $s$ in the second period ($I_{2ks}$) cannot be greater than the inventory of output $k$ ($I_{1k}$) carried over from the first period plus output $k$ produced in state of nature $s$ using different combinations of crop technologies ($b_{kjs} y_j$) plus the amount of grain $k$ purchased ($B_{2ks}$) in the corresponding state of nature $s$ during the second period.

Production of output $k$ harvested in the second period is subject to the resource constraints as follows:

$$\sum_j y_j \leq K \tag{4.5}$$

Equation (4.5) defines the land constraint. The sum of areas allocated to the different crop technologies ( $y_j$ ) must be less or equal to the total land availability (*K*).

$$\sum_j a_{ij} y_j \leq x_i \tag{4.6}$$

Equation (4.6) is the constraint on total purchased input availability. Input $i$ used ( $a_{ij}$ ) for the different crop production systems $j$ is ( $y_j$ ) set to not exceed the amount of input $i$ available ( $x_i$ ).

$$x_l + l^o \leq L^h + H \tag{4.7}$$

In equation (4.7) labor allocated to crop production system $j$ and ( $x_l$ ) to off-farm employment ( $l^o$ ) must be less or equal to the total family labor available ( $L^h$ ) and the amount of hired labor (*H*).

<u>Material Balance from the Hungry Season to the Next Harvest</u>

$$C_{3kst} + S_{3kst} + I_{3kst} \leq I_{2ks} + B_{3kst} \tag{4.8}$$

In this equation (4.8) another state of nature $t$ is added to reflect the price dynamic that occurred during the second period. Indeed, from the first harvest to the price recovery period (hungry season) prices of the main grain commodities that are millet, sorghum, maize increase across time and covary positively. The state of nature $t$ is conditional on the state of nature $s$ that occurred in the first period. We assume that at the beginning of the third time period, producers have full knowledge of the state of nature of yields and prices realized in the past periods. Hence, in the third period, the sum of consumption ( $C_{3kst}$ ), sales ( $S_{3kst}$ ) and inventory of output $k$ in state of natures $s$ and $t$ ( $I_{3kst}$ ) are restricted to not be more than the amount of cereal $k$ purchased in period 3 in state of nature $s$ and $t$ ($B_{3kst}$) and the transfer of inventory of output $k$ received from the second period in state of nature $s$ ($I_{2ks}$). The cash balances corresponding to each set of material balance are defined below.

### 4.4.2. Cash Balances

The cash balances guarantee an equilibrium state between the financial resources and the uses in each marketing period. We defined three cash balance equations:

Cash Balance in the First Period

$$E_1 + \sum_{i \neq K} c_i x_i + \sum_k p^b_{1k} B_{1k} + R_1 \leq F + \sum_k p^s_{1k} S_{1k} \tag{4.9}$$

Equation (4.9) represents the cash constraint for the first period. The cash and any liquid asset ($F$) plus the value of output sold in the first period ($p^s_{1k} S_{1k}$) is used to satisfy household expenditures ($E_1$), input purchases ($x_i$) except labor and land, expenses on grain for home consumption ($p^b_{1k} B_{1k}$). Remaining cash ($R_1$) is carried over the next period. Cash and liquidity assets include any sales of livestock that occur to finance some emergency expenditure such as health expenses and/or food purchases mainly during a bad state of nature.

Cash Balance in the Second Period

$$E_2 + \sum_k p^b_{2ks} B_{2ks} + R_{2s} + H \leq \sum_k p^s_{2ks} S_{2ks} + R_1 \tag{4.10}$$

Equation (4.10) states that the cash generated from the second period output sales ($p^s_{2ks} S_{2ks}$) in a given state of nature $s$ and the retained cash from the first period is allocated to the necessary household expenditures ($E_2$) (school fees, debt and taxes repayment, wages for migrant labor, heath expenses, social ceremonies), to hire labor

($H$), and for the grain purchases ( $p_{2k}^{b} B_{2ks}$ ). Again, retained cash ( $R_{2s}$ ) from the second period in state of nature $s$ is transferred to the subsequent time period.

<u>Cash Balance in the Third Period</u>

$$E_3 + \sum_k p_{3kst}^{b} B_{3kst} + R_{3st} \leq \sum_k p_{3kst}^{s} S_{3kst} + R_{2s} \tag{4.11}$$

In equation (4.11), the cash revenue from the sales of output in state of nature $s$ in the third period ( $p_{3kst}^{s} S_{3kst}$ ) and the retained cash from the second period in the identical state of nature $s$ must at least covered household expenditures ( $E_3$ ), grain purchases needed in the third period ( $p_{3kst}^{b} B_{3kst}$ ). Any excess of liquidity will be in the form of retained cash ( $R_{3st}$ ).

The risk aversion behavior of households has been reflected in the constraints to secure enough grain for their subsistence in each period (equation 4.12) and to fulfill a harvest income goal (equation 4.13) which corresponds to income requirements at harvest to pay for school fees, taxes, debt, naming ceremonies, etc. We defined a minimum level of total grain consumption for each period based on household surveys ’results. The harvest income requirement is defined obviously at harvest. Those constraints are satisfied before the expected profit is maximized.

$$\sum_k C_{Tk} \geq \underline{C}_{Tk} \tag{4.12}$$

$$\sum_k p_{2k}^{s} S_{2k} \geq HI \tag{4.13}$$

4.4.3. Objective Function

After specifying the constraints on cash and grain inventory in each period, the objective function can be written as follows:

$$\sum_s \sum_t \sum_r \rho(s).\rho(t|s)\rho(r|t|s)|\Psi_{str} \qquad (4.14)$$

$$\Psi_{str} = \sum_k \left[ (p^s_{1k} S_{1k} - p^b_{1k} B_{1k}) + (p^s_{2ks} S_{2ks} - p^b_{2ks} B_{2ks}) + (p^s_{3kst} S_{3kst} - p^b_{3kst} B_{3kst}) + w^s l^o + p^s_{kstr} I_{3kst} \right]$$
$$- \left[ \sum_{i \# K} c_i x_i + w^s H + E_1 + E_2 + E_3 \right] \qquad (4.15)$$

The objective function to be maximized is the expected end period wealth (equation 4.14). It is a function of the profit across the different periods in the planning horizon and the joint probabilities of states of nature *s*, *t* and *r*. *r* is the probability of the price state of nature for the end of the hungry season. Yield and prices are both random variables with yield and prices at harvest having a probability distribution of $\rho(s)$, post-harvest recovery price carrying a probability distribution of $\rho(t)$ and post-harvest price in the hungry season having a probability of $\rho(r)$. The sum of the probabilities of states of nature *s*, *t* and *r* is equal to 1. Equation (4.15) details the profit maximized in equation (4.14) as the difference between the sum of the net revenue earned in each period from the net grain sales less costs from the cropping activities, plus wages from non-farm work. Estimation of this farm household model using only the present traditional technologies gives the optimal crop mix, quantities of grain purchased, inventories of stock over the planning horizon and household's profit prior to the introduction of new cereal agricultural practices. This first model is the base case scenario.

We will use it to measure the impact of the use of intensive level of inputs (fertilizer, urea, and improved sorghum seeds) and government policies on the decision variables and the farm income.

Variable Definitions

| Item | Notation |
|---|---|
| $j$ | combination of crop and technology |
| $i$ | inputs used (fertilizer, urea, pesticides, herbicides, insecticides, seed) |
| $y_j$ | area devoted to production system $j$ |
| $a_{ij}$ | use of input $i$ by production system $j$ |
| $b_{kjs}$ | yield per unit of area for output $k$ |
| $T$ =1, 2, 3 | planting period, harvest and up to the next harvest |
| $s$ | state of nature of yield and prices at harvest |
| $t$ | state of nature of price between harvest and second planting |
| $C_{Tk}$ | Consumption during period $T$ for output $k$ |
| $S_{Tk}$ | Sales during period $T$ for output $k$ |
| $I_{Tk}$ | Output $k$ inventory for period T |
| $Q_{1k}$ | Starting inventory for output $k$ |
| $B_{Tk}$ | Quantity of output $k$ purchased in period $T$ |
| $E_T$ | Expenditures in period $T$ |
| $p^s_{Tk}$ | Selling price of output $k$ in period $T$ |
| $p^b_{Tk}$ | Buying price of output $k$ in period $T$ |
| $R_T$ | retained cash in period $T$ |
| $K$ | Total area of land available |
| $x_i$ | Total quantity of input $i$ available |
| $x_l$ | Labor allocated for crop activities |
| $c_i$ | Cost of input $i$ per unit of hectare |
| $l_j$ | labor allocated to the production system $j$ |
| $l^o$ | labor allocated to off-farm activities |
| $L^h$ | Total amount of family labor available |
| $H$ | Total amount of hired labor |
| $\rho_s$ | Probability of state of nature $s$ |
| $\rho_t$ | Probability of state of nature $t$ |
| $\rho_r$ | Probability of state of nature $r$ |
| $\underline{C}_{Tk}$ | Minimum consumption level for grain $k$ in period T |
| $HI$ | Harvest income goal |
| $\Psi_{str}$ | Profit maximized in state of nature $s$, $t$, and $r$ |

## 4.5. Data

Data used in the model came from a combination of primary and secondary observations. Primary data have been collected from a field survey conducted in 2008 and supplemented by additional field research in the months of June and July 2010 in the village of Garasso which is part of the district of Koutiala. The surveys were designed to analyze the income effects of improved sorghum technologies and traditional farming practices on the population of 100 farmers participating in the IER-INTSORMIL program in Garasso. So, a stratified random sample has been defined along the homogenous group of farmers participating in the program and 54 percent of the total number of farmer members of the IER-INTORMIL program has been interviewed.

The primary data collected included household expenditures, consumption, inventories, output sales, grain purchases, farm labor, agricultural input quantities and costs, land allocation. Secondary data were aggregate information in Koutiala from 1998 to 2008, gathered from the Ministry of Agriculture in Mali and the “Compagnie Malienne pour le Développement du Textile” (CMDT). Prices data for the main crops of the model are monthly observations covering the time frame 1998 to 2008 and were obtained from the National Market Watch in Mali. Those prices have been deflated using a GDP index for the same time period obtained from the International Monetary Fund (IMF). Rainfall observations in Koutiala for the time span 1980 to 2009 have been collected with the State Department of Meteorology. The labor coefficients used in the model were developed from the household survey and confirmed by field observations from Coulibaly et al. (1998).

## 4.6. Summary

The Discrete Stochastic Model has been chosen as modeling framework because it captures the sequential production cycle and marketing decisions in a stochastic environment. The stochastic process is related to randomness of yields and grain prices. Grain yields are influenced by rainfall while cotton yields are dependent besides rainfall on the annual prices announced by the CMDT. Seasonal price variation and conditional price distributions were captured through OLS regressions using retail market price data from the years 1998 to 2007/2008. Farmers' decisions regarding land allocation, input uses, grain consumption, marketing and cash flow are assumed to be made at the beginning of every marketing period based on realization of the current random variables and farmers' expectations about the future. The development of the empirical model maximizes expected wealth at the end of the planning horizon subject to resource constraints. The model also considers satisfaction of subsistence constraints and harvest income goals as farmers' means of revealing their risk aversion. The data needed to estimate the model were collected from primary household survey data and supplemented by secondary observations.

In the next chapters, the model will be used to evaluate the household income effect of the adoption of improved sorghum technologies and marketing strategies as well as various policy measures to restore the cotton sector.

# CHAPTER 5: TRADITIONAL TECHNOLOGY AND MODEL PERFORMANCE

This chapter discusses the model results for the traditional technologies of cotton, maize, sorghum and millet. The results of the model are validated with empirical observations and observed farmers' decision making. First, the model findings will be compared with farm survey data and results of other recent studies. Then, the ability of the model to predict farmers' behavior in response to changes in cotton prices and fertilizer costs will be evaluated.

For the first step of the model validation, we run the model with the cotton price and fertilizer prices for the crop season 2008/2009 as the farm household data were collected during that crop season. We will compare the model results with field observations and other research studies in the same agro-ecological zone. Then, in the second step, we use the 2011 cotton price and fertilizer costs to predict farmers' acreage response and the income effect of those policies with the traditional technologies.

## 5.1. Calibration and Validation of the Model

Running the model for the cotton price of 2008, the model allocates 3.7 ha to cotton, 2 ha to maize, 6.3 ha to sorghum and 3 ha to millet (see table 5.1). The large share of sorghum in the crop mix results from sorghum's role as the major staple grain in the household. Outside of the primary cotton zone with higher rainfall, sorghum has a comparative advantage over maize because sorghum is more flood, drought, and low soil fertility tolerant than maize.

The model results match fairly well our empirical field observations where the average farmer allocates 4.2 ha to cotton, 2.8 ha to maize, 5.2 ha to sorghum and 2.8 ha to millet. This is not surprising as the data in the model construction have been used to calibrate the empirical field observations.

The model results for the traditional technologies are compared with other empirical studies in the Sudano-Guinean region of Mali. Baquedano et al. (2010) analyzed the impact of the removal of US cotton subsidies on farm household income in Mali. Under traditional technologies, Baquedano et al. (2010) found that Malian farmers allocate 3.6 ha to cotton, 5.8 ha and 1.0 ha to sorghum and maize, respectively. Coulibaly et al. (1998) studied the impact of devaluation on new technology adoption in this cotton zone. They estimated that on average farmers grow 3.0 ha of cotton, 6 ha on sorghum and 0.5 ha on maize and 2 ha on millet. These latter results are for moderate risk averse farmers. We also handle risk aversion by including constraints to satisfy subsistence consumption and the harvest income goal. Both constraints are expressed as priorities by farmers in their decision making.

As in our study, sorghum is the principal cereal activity and the land allocations to the different crops are very similar to our findings.

Table 5.1: Validation of the Model with Average Farm Data and Model Results

| Traditional Crop Technologies | Average Farm Surveyed | Model's results Cotton Price=200 F CFA/kg |
|---|---|---|
| Cotton (ha) | 4.2 | 3.8 |
| Maize (ha) | 2.8 | 1.9 |
| Sorghum (ha) | 5.2 | 6.3 |
| Millet (ha) | 2.8 | 3.0 |
| Total Area (ha) | 15 | |
| Total minimum household grain consumption (kg) | | |
| Period 1[a] | 5103 | |
| Period 2[b] | 3645 | |
| Period 3[c] | 2916 | |

Note: [a]Period 1 corresponds to the agricultural season
[b]Period 2 corresponds to the price recovering period
[c]Period 3 is the lean season.
Source: Model Results

The crop mix identified in this previous section is mainly driven by the announced cotton price at the beginning of the agricultural campaign, the fertilizer costs and the need to satisfy a minimum grain consumption requirement. Now, we will analyze how the cotton seed price and fertilizer costs have changed recently and how the traditional system has responded to these changes. Indeed, in 2011, two major changes took place in the Malian agricultural economy, the extension of the fertilizer subsidy to sorghum and millet and the substantial increase in the cotton farm gate price of 31 percent relatively to the real price of cotton in 2008.

## 5.2. New Economic Environment of Fertilizer Subsidy and Substantial Increase in Cotton Price in Mali

With the debt crisis of the 1980s in developing countries the World Bank and the International Monetary Fund (IMF) began putting substantial pressures on developing countries to eliminate subsidies and privatize the fertilizer market that was under the control of state-owned companies most commonly cotton parastatal. Fertilizer was widely distributed to farmers with government agricultural credit which resulted in high fiscal costs and inefficiency in the distribution process marked by many delays in the supply of fertilizer to farmers. As in most African countries, under the structural adjustment programs Mali had to reform their fertilizer market by allowing more competition from the private sector. Moreover, fertilizer and other subsidies in agriculture including on credit were eliminated in Mali during the 1990s.

In 2005, the Malawi government designed a targeted fertilizer voucher program entitled Agricultural Inputs Subsidy Program (AISP) to enhance maize production and farmers' income. In the AISP, targeted farm households[9] received 2 subsidized coupons of 50 kg of fertilizer (NPK and Urea). With the subsidized coupons, farmers were only paying 28 percent of the market price of fertilizer, the remaining 72 percent were paid by the government (Dorward et al. 2008). Along with the fertilizer subsidy, maize hybrid

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[9] According to the program objectives, households receiving the coupons were poor farmers with severe liquidity constraints, but in practice this was not always respected (Dorward et al.2008).

cultivars were also available at discount prices. With the combination of factors including good weather conditions and the use of improved maize cultivars, the AISP led to a significant increase in maize productivity, food availability and economic growth. Maize production more than doubled and the value of the agricultural sector in the GDP was raised from US$ 3.2 million before 2005 to US$ 11.1 million in 2006 and 2007 (Dorward et al. 2008).

After Malawi's success in raising maize yields with fertilizer subsidies, the World Bank position on the fertilizer subsidy changed. The World Bank position now is that developing countries have the right to follow their own policy initiatives and implement fertilizer subsidy programs. If there is another crisis similar to the one that led to the structural adjustment movement, we can expect the World Bank and the IMF to again apply pressure against subsidies. For the moment there is an understanding that developing countries need to increase their own food production and that fertilizer use is a critical element to do that. The argument for a fertilizer subsidy is a learning by doing or infant industry argument. As farmers learn to better use fertilizers and combine them with new cultivars and better agronomy, there will be a higher return over time and subsidies will not be necessary.

Hence, the Malawi success story has encouraged many developing countries to follow this program of subsidizing fertilizer. Moreover, in the Abuja meeting in 2006 African policy makers decided to improve fertilizer access through targeted subsidies with special attention to poor farmers. [10] The fertilizer subsidy program was also encouraged by the sharp increase in commodity prices in 2007 and 2008 as the result of the international food crisis during those years and the consequent pressure on developing countries to raise crop yields in the agricultural sector.

In response to the regional call for stimulating agricultural production in Africa, the Malian government began providing subsidies for rice production in 2008. Then these subsidies were expanded in 2009 to include cotton, maize and wheat. Finally in 2011, after complaints from producers' organizations and NGOs, sorghum and millet were also

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[10] In 2006, African Union leaders signed a declaration during the Africa Fertilizer Summit in Abuja to stimulate an African Green Revolution through incentives to use fertilizer in Africa.

eligible for the fertilizer subsidy program. The subsidy was provided through vouchers to farmers who redeem the voucher with a private supplier. The fertilizer dealer submits the voucher to the government for repayment of the price differential between the market price and the subsidized price.

Figure 5.1 below depicts the market prices for cotton fertilizer prices (NPKBS[11] and Urea) in Mali from 2003 to 2011 and the costs at which the CMDT supplied fertilizer to farmers during the same period of time. Fertilizer for cotton and maize are provided by the CMDT and private dealers supply fertilizer for the other crops. As we can observe in this figure, the market and CMDT fertilizer prices were at record levels in 2008 but prices retreated in 2009 and 2010 to their normal trend before the 2008 hikes. Then in 2011, fertilizer prices are resuming their 2008 hikes.

Before 2008, the CMDT fertilizer prices were aligned with market prices. After 2008, the CMDT fertilizer prices became much lower than the market prices because the government subsidized fertilizer for maize and cotton and then in 2011 millet and sorghum. The government subsidy in 2011 is 28 percent for NPK and 20 percent for Urea as compared to the average market price of 2011. Note that the subsidized price of fertilizer offered by the CMDT and generally received by sorghum and millet in 2011 returned to the pre-2008 market price levels. Also note that Urea costs have dipped as natural gas has become cheaper. The high other fertilizer prices are influenced by the commodity price spike of recent years. As that comes down so will fertilizer prices.

[11] The cotton fertilizer compound NPKBS is different from the cereal compound in the fact that it contains boron and sulfur in addition to nitrogen, phosphorus and potassium. Boron and sulfur are two essential nutrients for the growth of cotton. Prices for the NPKBS for cotton are slightly higher than the NPK for the cereals but variation of prices over time for these two types of commodities are similar.

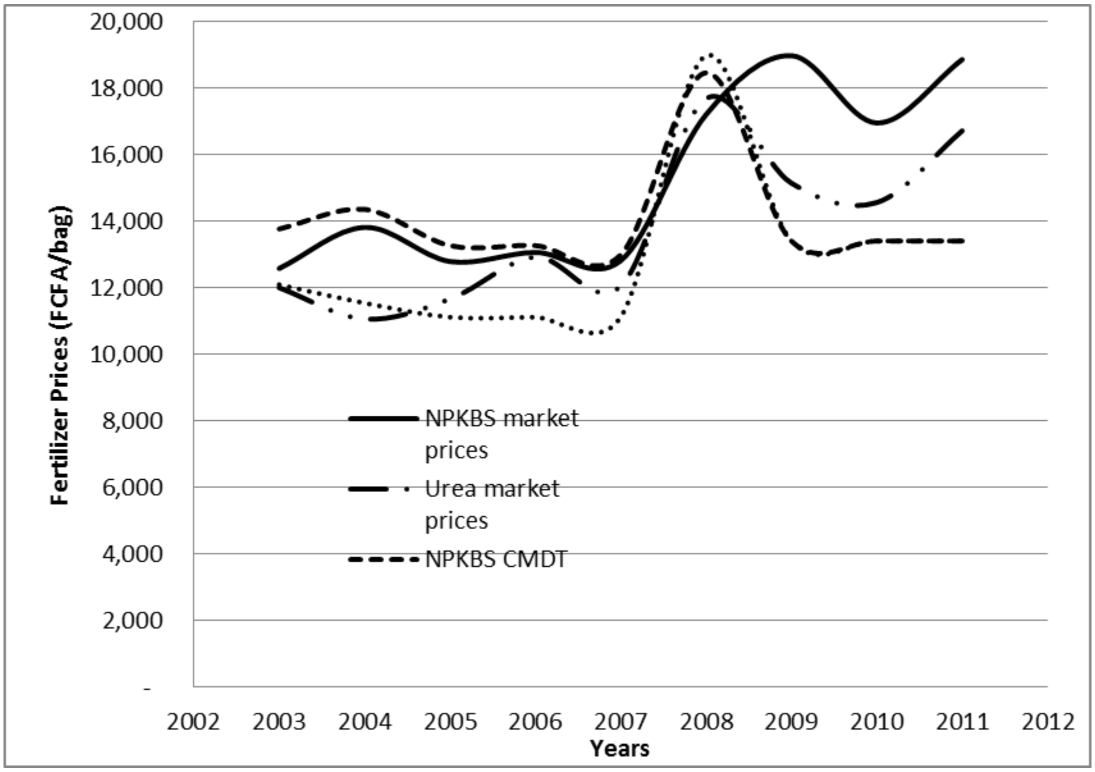


Figure 5.1: Market and CMDT Prices for Cotton Fertilizer (NPKBS and Urea) from 2002 to 2011

Source: CMDT, 2011

Regarding the cotton seed prices, since 2005, the farm gate cotton price is fixed by the government based on world cotton price of the previous year. [12] Normally, the cotton price is set in negotiation between the CMDT and farmers' union representatives before the start of the crop season. The CMDT plays a very influential role in defining the domestic cotton price as farmers are poorly informed about the world cotton price and trends (OECD 2006). As we can observe from figure 5.2 below, fluctuations in the world

[12] The world cotton prices are the season average Cotlook Index A. An index is published every year by the International Cotton Advisory Committee (ICAC). The prices were originally in $US/lb but they have been converted to $US/kg in this study for comparison purpose. The Malian cotton prices are the farm gate cotton prices reported by the CMDT. The prices were converted to lint equivalent $US/kg using a seed/lint ratio coefficient of 0.42 (Alston et al. 2008) and an average annual exchange rate published by the USDA Economic Research Service (www.ers.usda.gov/Data/ExchangeRates).

price have been transmitted to the domestic farm gate price but with a lag strongly favoring the CMDT. After a decade of slowly increasing world prices (nominal), in 2010 the world price more than doubled (ICAC, 2010). However even with the lagged catch up in 2011, the farm gate price increased by only 48 percent above the 2009 Malian price level. The Malian cotton price increased from $ US/kg 0.35 to $US/kg 0.51 from 2010 to 2011.

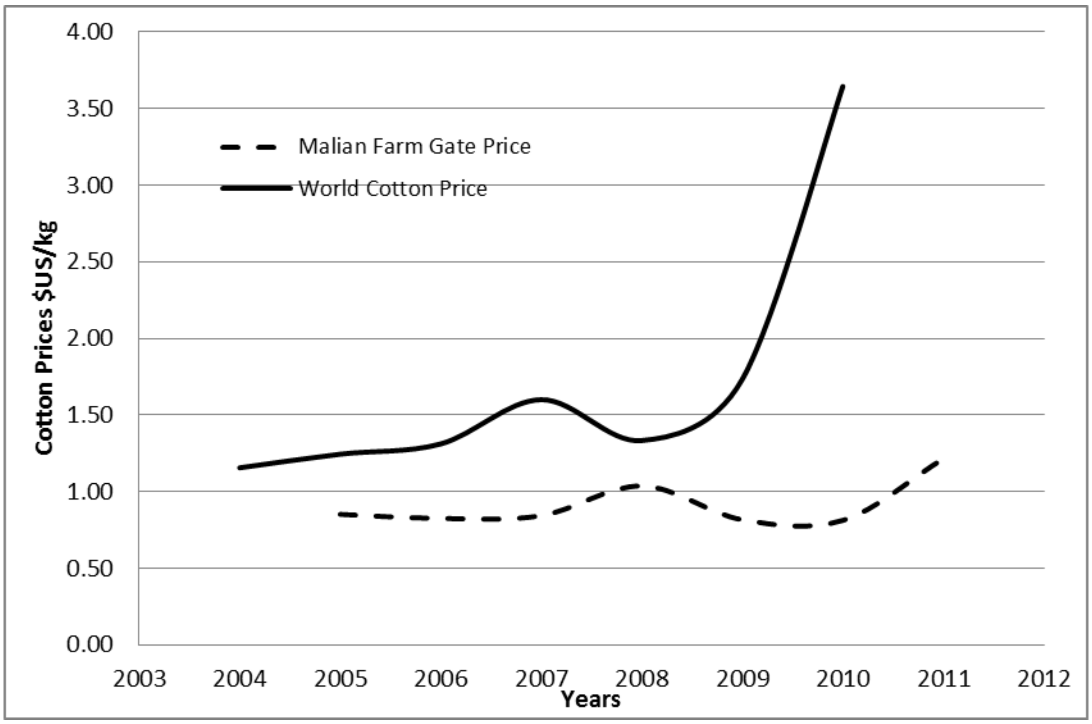


Figure 5.2: World and Malian Nominal Cotton Prices in Lint Equivalent from 2004 to 2011

Source: ICAC 2011 and CMDT 2011

## 5.3. Model Prediction of Farmers' Response to the Increase in Cotton Price and Fertilizer Subsidy without and with Grain Marketing Strategy

Farmers generally sell at harvest to satisfy pressing household expenditures and make very little sales of grains during the post-harvest season. Those small sales are usually called consumption because the purpose of those sales is to buy some items to complement domestic grain consumption. In the first runs all cereals are sold at harvest.

Without the opportunity for farmers to sell cereals during the post-harvest period the combined effect of substantial increase in the cotton price and the access to fertilizer subsidy translate into a large expansion of the cotton and maize planting areas. Cotton and maize planting areas increase by 43 percent and 154 percent, respectively (table 5.2). The acreage expansion for cotton leads to a decrease in total area planted for cereals. Traditional sorghum area is the principal cereal crop affected by these price changes of 2011 for cotton and fertilizer. The area of sorghum is drastically reduced[13] by 72 percent. As a result, farmers are reallocating land and family labor resources to the most profitable crops which are in this case cotton and maize.

Maize area is very responsive to the increase in the availability of fertilizer subsidy. With the increased price for cotton the maize producers also have an incentive because this makes more credit available for maize (an allowed option with the cotton input financing), and it is easier to repay with the higher cotton price. The maize input credit has to be repaid in cotton.

Maize substitutes for sorghum in home consumption (see figure 5.3). The growth in cotton production and sales at a high price leads to a high household wealth estimated at 1,206,482 F CFA ($ 2,666), a 49 percent increase in household wealth.

The availability of more maize and cotton for sales ease the liquidity constraints at the end of the planning horizon (table 5.2). With less sorghum production, the marginal value of the sorghum balance constraint increases by an additional 56 F CFA/kg ($0.13 $/kg) relatively to the 2008 economy.

Farmers' response to the new economic environment is then analyzed allowing the marketing strategy for sorghum and then for all grains. The marketing strategy selected consists of storing the grains and selling after the price recovery and before the next planting season. By selling during the price recovery period farmers can take

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[13] Since millet is concentrated on the poorer soils and there is less technology available than for either sorghum or maize we consider its supply to be inelastic.

advantage of the normal seasonal price increase especially during a bad year of production (figures 3.1 and 3.2 in chapter 3).

With the higher price for sorghum from selling sorghum later, the area for traditional sorghum is extended at the expense of the maize area. Income increases further but only by 2 percent over the gains obtained from the cotton and maize improvements without marketing practices of sorghum. But sorghum has shown its potential to compete in the crop system even with the favorable conditions for cotton and before the new sorghum technologies are introduced. When maize and millet are also sold later in the season, farmers have a greater incentive to expand the maize area to substitute for sorghum. The overall wealth effect is an additional increase of 3 percent compared to the previous case identified by the marketing strategy for sorghum.

In the 2011 economy or when the marketing strategies are adopted for all grains, there is less variability in the distribution of income as revealed by the lower standard deviation (table 5.2). So, higher cotton price and the late sales of grains enable farmers to secure consistently enough income throughout the year.

With more grain marketing opportunities there is a further easing of the cash constraint during a bad crop year. Farmers' ability to sell their grains later in the season increases the return on storage as depicted by the higher marginal value of the grain balance constraint at the end of the harvest period (table 5.2).

Table 5.2: Farmers' Response to the 2011 Economy with their Traditional Technologies and the Opportunity to Implement Marketing Strategy

| Traditional Crop Technologies | Base Case<br>TT<br>No MS<br>2008 Economy | Scenario 1<br>TT<br>No MS<br>2011 Economy | Scenario 2<br>TT<br>MS for Sorghum<br>2011 Economy | Scenario 3<br>TT<br>MS for all Grains<br>2011 Economy |
|---|---|---|---|---|
| Cotton Price | 200 | 231 | 231 | 231 |
| Cotton Area (ha) | 3.8 | 5.42 | 5.02 | 5.29 |
| Percentage change | | 43% | 32% | 39% |
| Maize Area (ha) | 1.9 | 4.82 | 3.83 | 5.99 |
| Percentage change | | 154% | 102% | 216% |
| Sorghum Area (ha) | 6.3 | 1.77 | 3.15 | 0.71 |
| Percentage change | | -72% | -50% | -89% |
| Millet Area (ha) | 3 | 3 | 3 | 3 |
| Total Area (ha) | | 15 | 15 | |
| End Wealth (F CFA) | 808,386 | 1,206,627 | 1,222,705 | 1,247,780 |
| Percentage change | | 49% | 51% | 54% |
| Expected Marginal Value Grain Balance at Harvest (CFA/kg) | | | | |
| Maize | 23,624 | 20,006 | 20,925 | 21,120 |
| Millet | 27,174 | 26,673 | 26,671 | 27,001 |
| Sorghum | 24,995 | 25,051 | 26,134 | 26,197 |
| Minimum Wealth (CFA) | 1,329 | 199,076 | 163,569 | 148,806 |
| Maximum Wealth (CFA) | 2,525,354 | 2,505,395 | 2,874,063 | 2,909,505 |
| Standard Deviation of Wealth (CFA) | 535,692 | 479,592 | 521,546 | 514,279 |
| Max Marginal Value of Cash in Period 2 | 1.79 | 1.41 | 1.31 | 1.34 |
| Max Marginal Value of Cash in Period 3 | 7.94 | 4.71 | 2.07 | 1.36 |

Source: Model Results
Exchange rate: 1 $ US =452.61 F CFA on April 18, 2011 at www.oanda.com
Note: TT= Traditional Technology, MS= Marketing Strategy

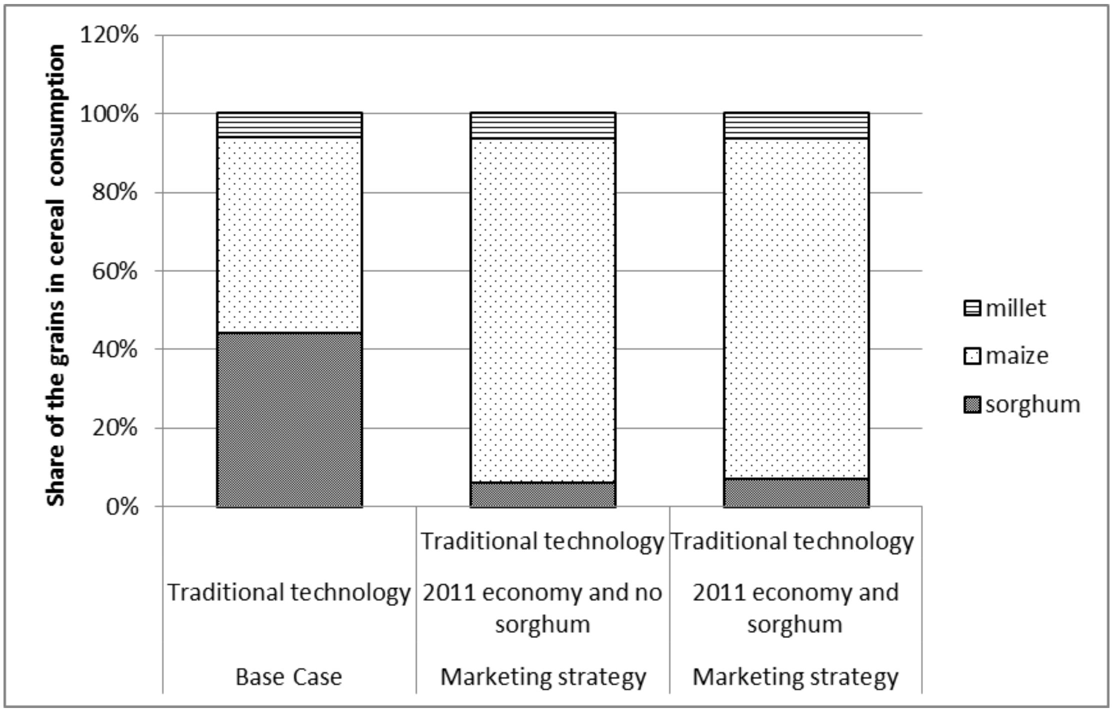


Figure 5.3: Substitution in Consumption of Cereals across Policy Scenarios
Source: Model Results

## 5.4. Summary

The 2011 Malian government pricing policy on cotton and the fertilizer subsidy led to large improvements in the household wealth. But, farmers still have a long way to catch up for their share of the large increase in the world cotton price. The substantial increase in cotton price is expected to trigger growth in cotton areas. The maize sector will also benefit substantially from the fertilizer subsidy and the increased access to fertilizer. Sorghum areas retreat significantly as cotton and maize are expanding. Similarly, if all grains can be stored and sold later, farmers pick maize for these sales and traditional sorghum decreases substantially.

Allowing only sorghum to be stored and sold later has a very small effect on incomes (as does storage of all grains) compared to the other changes in economic policy going on, specifically the increased cotton price and the fertilizer subsisdy. In the next chapter we will add to the 2011 economy the new sorghum technologies.

# CHAPTER 6: IMPROVED SORGHUM TECHNOLOGIES AND MARKETING STRATEGIES

We saw in the previous chapter that the 2011 cotton pricing policy and fertilizer subsidy led to substantial household wealth and cotton acreage response. Farmers were diverting from local sorghum into maize and cotton. However, the opportunity to sell their sorghum later in the year and to receive higher prices particularly during adverse years of production increased the incentive to crop traditional sorghum and slightly increased incomes.

In this chapter, we describe first the improved sorghum technology now available in the region. Next, the sorghum technology is introduced in the model without and then with marketing strategies and we estimate the resulting income effect and acreage response from technology alone and technology with marketing.[14] The new sorghum technology-marketing scenarios will be analyzed with the 2011 economic conditions. We also compare the model results with some field observations of farmers collected in 2011 during a following–up visit. Finally, we make some concluding observations.

## 6.1 Improved Sorghum Technologies

The improved sorghum technology consists of a higher yielding cultivar of sorghum, use of moderate levels of fertilizer in the following quantities, 50 kg of Di-Ammonium Phosphate (DAP), 50 kg of Urea and 10 kg of seed of the improved sorghum cultivar. In addition to inorganic fertilizer, the Production-Marketing project of

[14] Note that we already considered marketing alone in the previous chapter.

INTSORMIL included a package of agronomic recommendations including organic manure, ridging, side-dressing, the split application of fertilizer and thinning. The principal components of the technology were the improved caudatum[15] sorghum, Grinkan, and the moderate fertilizer levels. The improved sorghum variety responds well to inorganic fertilizer and expected yields for average farmers are 50 to 100 percent higher than the traditional variety. For the best farmers, yield gains go up to three times those of the traditional cultivars. These yield gains were derived from field investigations and from researchers' estimations (Coulibaly 2010). Compared to cotton, average yield of the improved sorghum is one and half times above traditional cotton yields. But the average traditional maize yield is 7 percent higher than the mean yield for the improved sorghum (see table 1.2).

Due to liquidity constraints farmers need access to bank loans for the purchase of fertilizer for the improved sorghum cultivar as they do for cotton and maize. Producers have to operate in farmers' associations to obtain the lower price of credit of 12 percent[16] from the BNDA (National Bank for Agricultural Development) and there is a credit ceiling of 150,000 F CFA/ha ($/ha 332 at the exchange rate of 452 F CFA/ $US). Farmers can pay back their bank loans by selling their grains after prices recover from the harvest collapse since the bank loans are for ten months. Based on historical experience, expected prices increase 26 percent from the harvest price to the second price period, approximately four months later. So, by selling their grains after harvest, farmers can obtain a substantial return on storage and later sale.

## 6.2 New Sorghum Technology in the Model with no Marketing Strategy

With the introduction of the improved sorghum technology in the model without the marketing strategy, the traditional sorghum is entirely replaced by the new sorghum technology. By adopting the new sorghum technology even without better marketing, the household wealth is enhanced by 16 percent over the base case at the 2011 prices (table 6.1).

[15] Actually a cross between Guinea and Caudatum with 25 percent Guinea and 75 percent Caudatum.

[16] The normal bank interest rate is 24 percent. The lower interest rate is given to the producers' associations because of the reduced risk premium when lending through a famers' association. There may also be some subsidy from this public institution to support farmers' associations.

Table 6.1: Results of the Adoption of Improved Sorghum Technologies without and with Marketing Strategy under the 2011 Agricultural Economy

| Traditional Crop Technologies | Base Case TT No MS 2011 Economy | Scenario 2 IST No MS 2011 Economy | Scenario 3 IST MS for Sorghum 2011 Economy | Scenario 4 IST MS for all Grains 2011 Economy |
|---|---|---|---|---|
| Cotton Price (CFA/kg) | 231 | 231 | 231 | 231 |
| Cotton Area (ha) | 5.42 | 4.6 | 4.4 | 3.5 |
| Percentage change | | -16% | -20% | -36% |
| Maize Area (ha) | 4.82 | 3.4 | 3.6 | 4.5 |
| Percentage change | | -28% | -24% | -6% |
| Sorghum Area (ha) | 1.77 | 0 | 0 | 0 |
| Percentage change | | | | |
| Millet Area (ha) | 3 | 3 | 3 | 3 |
| New Sorghum | | 4.0 | 4.0 | 4 |
| Total Area (ha) | 15 | 15 | 15 | 15 |
| Expected Wealth (x1000 CFA) | 1,206 | 1,394 | 1,444 | 1,457 |
| Percentage change | | 16% | 20% | 21% |
| Marginal Value of the IST Credit Constraint | - | 0.75 | 1.32 | 1.28 |
| Expected Marginal Value Grain Balance at Harvest (CFA/kg) | | | | |
| Maize | 20,006 | 22,499 | 21,492 | 21,727 |
| Millet | 26,672 | 26,754 | 26,690 | 27,096 |
| Sorghum | 25,051 | 24,947 | 26,147 | 26,117 |
| Minimum Wealth (x1000 CFA) | 199 | 227 | 105 | 72 |
| Maximum Wealth (x1000 CFA) | 2,505 | 3,458 | 3,964 | 4,272 |
| Standard deviation of wealth(x1000 CFA) | 480 | 702 | 749 | 816 |
| Max Marginal Value of Cash Period 2 | 1.41 | 1.69 | 1.41 | 1.69 |
| Max Marginal Value of Cash Period 3 | 4.71 | 6.39 | 3.32 | 1.36 |

Source: Model Results
Exchange rate: 1 $ US =452.61 F CFA on April 18, 2011 at www.oanda.com
Note: TT= Traditional Technology, MS= Marketing Strategy

The new sorghum gives higher yield response under intensive input levels compared to the traditional varieties. The traditional tall sorghum cultivars lodge with higher fertilizer use.

Thus farmers new crop portfolio is composed of all intensive crops that require fertilizer use with the exception of millet.[17] On the best lands, the improved sorghum is competing with cotton and maize in land allocation. The fact that farmers do not have to reimburse their input loans for sorghum at harvest when prices are at their lowest levels leads to higher returns of the improved sorghum. Here they do not have the option to market later but can keep the sorghum for consumption over the crop year. With the new technology farmers are diverting land and family labor from maize and cotton to grow 4 ha of the improved sorghum.

The area cultivated for the improved sorghum could have even been higher if farmers were not limited in the amount of credit they could borrow. Indeed, the marginal value of the credit constraint shows an opportunity cost of 0.75. This means that if farmers had an additional 1 F CFA available they would have purchased more fertilizer to grow sorghum and increase their wealth by 0.75 F CFA. So, the shadow value of the credit constraint indicates a return of 75 percent on the marginal increase of credit. This return is higher than the interest rate on the bank loans for the purchase of fertilizer for sorghum and reveals consequently the high profitability of the improved sorghum as well as the limiting nature to farmers of the credit constraint when the new sorghum technology is available.

Sales of sorghum at harvest become very important especially with the low cotton yields. As discussed previously farmers have important cash requirements at harvest. With the introduction of the new sorghum, there is more flexibility in the pattern of grain consumption, sales and purchases. More sorghum is sold during years of higher harvest price of sorghum relatively to maize. Consumption of sorghum substitutes for maize particularly when the harvest price of sorghum is less attractive than the maize price.

[17] Millet area stays constant in the crop mix because millet is traditionally grown on poor lands and is the only produce in the crop mix that can respond reasonably well on these poorer soils. However, many Malians prefer millet as a food so the harvest prices of millet are higher than those of sorghum and maize.

With the new technology farmers need to purchase less maize and sorghum for their home consumption (figure 6.1).

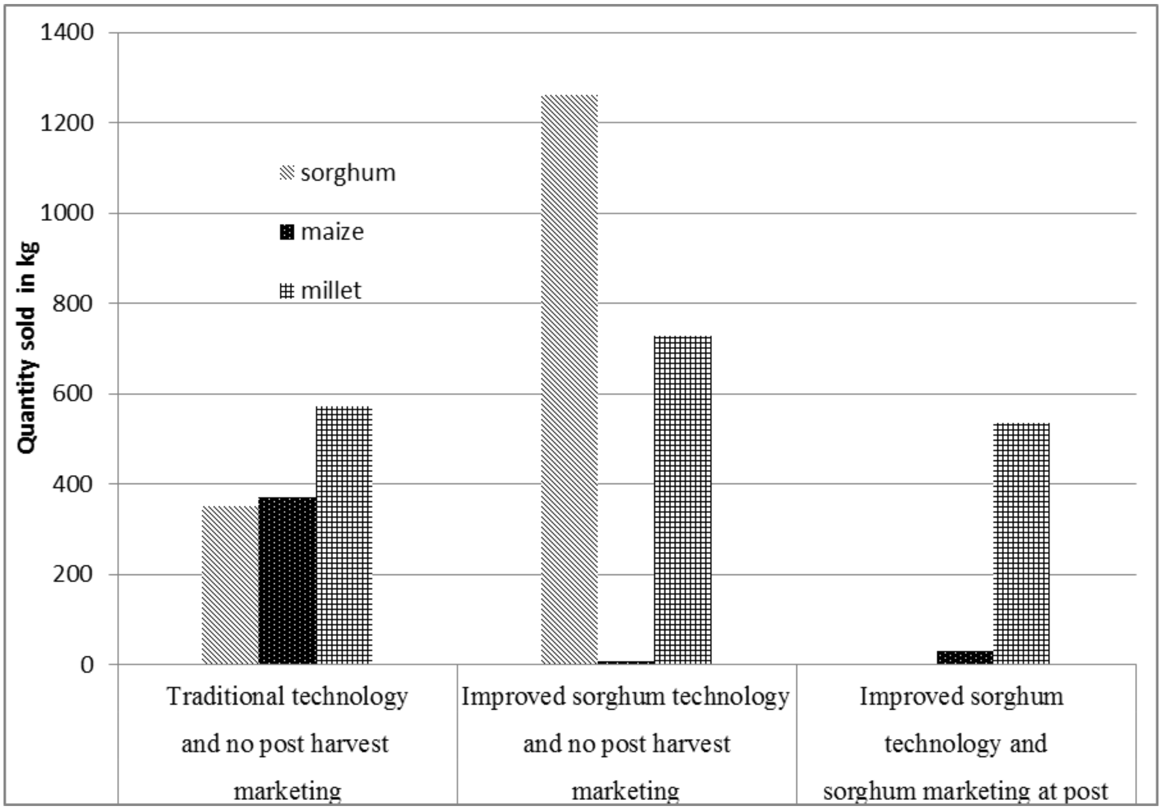


Figure 6.1: Expected Quantity of Grain Sold at Harvest across Policy Scenarios
Source: Model Results

With the introduction of the new sorghum technology, the marginal value of cash increases substantially (table 6.1) during poor states of nature of the new sorghum variety as farmers need money to satisfy their financial needs. So, farmers will have a higher incentive to store enough millet and maize for their consumption and household expenses. This is reflected in the larger marginal value of millet and maize grain balance constraints.

## 6.3 New Sorghum Technology in the Model plus the Marketing Strategy

The opportunity for farmers to sell sorghum in the price recovery period yields an additional 4 percent increase in the ending wealth relative to the previous case when farmers were only able to sell at harvest (table 6.1). The higher post-harvest prices for sorghum gave an increased incentive to farmers to postpone their sales of sorghum until the price recovery period (up to the next planting season) and increase their revenues. Hence, in figure 6.1, we see that no sales of sorghum occur at harvest when farmers can implement the marketing strategy. The stock of sorghum above consumption is carried into the price recovery period. The returns for the improved sorghum cultivar are increasing as revealed by the larger marginal value of the sorghum credit constraint.

The credit constraint for the improved sorghum is still binding and the marginal value of 1.31 indicates a 131 percent return on investment in expanding the sorghum area. If there were no input credit constraint, farmers would have increased the area allocated to the new sorghum above the 4 ha. We might ask whether given the credit constraint on increasing the land planted for the new sorghum cultivar, why farmers are still not cultivating the traditional sorghum to supplement the improved sorghum production and respond to the higher return on marketing sorghum. With the availability of the fertilizer subsidy and the high cotton price, farmers prefer to grow additional area of maize and sell at harvest prices thereby satisfying consumption objectives and enabling sorghum to be sold later. Thus, we notice that although the maize area is still lower than that of the base case scenario, there is a small positive area response of maize which increases by 4 percent compared to the case where post-harvest sales for sorghum did not occur.

The small increase in maize area comes at the expense of cotton area which is reduced for the maize area. Maize is competing with cotton for additional fertilizer resources and maize displays larger net returns during the very bad years of cotton production characterized by cotton yields below 800 kg/ha and a high harvest price for maize. Nevertheless, cotton still represents the largest area in the improved farming system. Note the constraint on the further increase of the sorghum area.[18] Also, with farmers' opportunity to adopt the improved marketing practices for all their grains, there is a slight increase in the household wealth and more competition between sorghum and maize in land allocation at the expense of cotton (table 6.1). Note that with the opportunity to store and sell all cereals more maize is produced and sold but there is no reduction of the sorghum area. Cotton area reduction now makes the increased cereals marketing more profitable. So the crux of the diversification decision is the increasing importance of both cereals.

The adoption of the improved sorghum and grain marketing strategies lead to higher income but there is more variability in the distribution of wealth around the expected value as revealed by the standard deviation of wealth (table 6.1). The decreasing marginal value of cash at the end of the marketing periods is an indication that farmers become less cash constrained when they are able to sell sorghum and the other grains later in the season at higher prices. Also, with the sorghum and the other grain marketing opportunities producers value more their stock of grains available at the end of harvest (table 6.1).

The model results with the adoption of improved sorghum and marketing strategy were compared with farmers' predictions regarding their land allocation during a field survey at the beginning of the 2011 agricultural campaign with a sample of 34 farmers in the study area. For the 2011 crop year, the interviewed farmers intend to allocate 4.8 ha of land to cotton, 3 ha both to maize and traditional sorghum, 2.9 ha to millet and 1.3 ha of land to the new sorghum. The model result overestimated the land allocated to the new sorghum and underestimated area in the traditional sorghum but they indicated a shift to the new sorghum technology. They also indicate how models adjust faster than farmers to new economic opportunities requiring some agronomic and marketing adjustments by farmers.

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[18] With a large scale introduction of the sorghum technologies we expect the sorghum price to fall. One result will be the increasing substitution of sorghum for maize in the rations for poultry and other animals. This scaling up of the sorghum technology and expanded use in poultry feed is expected to occur over the next five years.

## 6.4 Summary

Under the 2011 policy interventions, the opportunity for farmers to adopt the improved sorghum agricultural technologies leads to a substantial rise in household wealth. This increase is largely driven by the switch from the traditional sorghum technologies to the improved one and the resulting higher yield effect. The introduction of the improved sorghum in the farming system increases the opportunity costs of financial capital and suggests a need for a greater access to credit.

The prospect for farmers to take advantage of the price seasonality especially during adverse years by selling sorghum or maize later in the years has a positive but smaller impact on the household wealth as compared to the introduction of the improved sorghum cultivar and associated technologies. Combining both agricultural technologies for sorghum and marketing strategies produces the highest income effect due to the cumulative impact of the good fertilizer response of the new sorghum variety and the higher market prices.

Note that with both new technology and the marketing strategy farmers' returns are higher with sorghum than with cotton. In the region where this technology was introduced farmers in surrounding regions call Grinkan (the new sorghum cultivar) the "cotton of Garasso."

In the next chapter we consider what happens when the golden age of 2011 ends. Then cotton prices are expected to come back down and fertilizer subsidies eliminated.

# CHAPTER 7: BACK TO NORMAL: REMOVING THE FERTILIZER SUBSIDY AND RESPONDING TO THE EXPECTED DECLINE OF THE COTTON PRICE

The previous chapter analyzed farmers' response to the introduction of the improved sorghum with the economic conditions of 2011, including a substantial increase in the cotton price and the access to fertilizer subsidies for sorghum. In this chapter, we consider the return to the trend of world cotton prices and the elimination of the fertilizer subsidies. First, we review the economic forces driving the expected changes in the Malian cotton pricing policy and fertilizer subsidy program. Second, we simulate first the effect of the reduction of the high cotton prices and then we add in the increase in fertilizer costs. The cotton price comes down by 8 percent. Fertilizer prices increase by 24 percent with the elimination of the subsidies. Both scenarios are compared with the 2011 economic environment including the new sorghum technology and marketing changes.

## 7.1 Predicted Policy Change in the Cotton Price and Fertilizer Subsidy

The historic 2010 increase in the world cotton price has substantially increased cotton production in the big producer countries. World production is expected to rise by 8 percent in 2011 in most of the world producing countries except in the US (ICAC 2011). Even though cotton areas have grown significantly in the US, bad weather conditions in Texas, especially the drought have resulted in a substantial yield decline. So, US production is projected to decrease by 12 percent relative to 2010 (ICAC 2011). Cotton production in India, China and Australia, is expected to reach record levels. Thus, with the surge in world cotton supply of cotton, stocks will be replenished, import demand in large importing countries will be reduced and the overall effect will be a lower world cotton price than in 2010.

Furthermore, the decline in the world cotton price will also be driven by the output expansion with the increasing use of transgenic BT cotton and the continuing competition from synthetic fibers. The ICAC secretariat could not publish a price forecast for the year 2011 based on the price model because this model performs well only when the cotton price is in its historical range (ICAC 2011). However, based on the ending stock consumption ratio in China and the rest of the world, a price decline of 15 percent with respect to the 2010 price is expected (Commodities 2011).

We used a price elasticity method (Alston et al. 2007) to compute the elasticity of price transmission between the world cotton price and the farm gate lint equivalent cotton price from 2004 to 2011. We found a transmission elasticity of 0.54. During the time period 2004 to 2011, farmers receive 54 percent of the changes in the world cotton price. This elasticity coefficient is also very close to the 58 percent estimate of Baquedano et al. (2009). Then, we determined a base price at the Malian gin gate by translating the 2011 farm gate seed price into lint equivalent price. Based on the assumption of a 15 percent world price decrease in 2011, and the price transmission elasticity of 0.54, we found that the farm gate cotton lint price will decrease by 45 F CFA/kg ($/kg 0.1) or by 8 percent. When we translate the farm gate cotton lint price into cotton seed price we found that farmers will be paid 212 F CFA/kg ($/kg 0.47) in real price for the next agricultural season. So, this price will be used in the model to predict farmers’ response to a change in the farm gate price.

Table 7.1: Impact of a Decrease in the World Cotton Price on the Cotton Fiber Price in Mali

| World Price | Malian Fiber Price<br>Base Price[1]= 550 F CFA/kg ($/kg 1.22)<br>Elasticity of transmission= 0.54 | |
|---|---|---|
| Percent change | Absolute change (F CFA/kg) | Percent change |
| -15% | -45 ($/kg 0.1) | -8% |

Source: Author calculations
Note: [1]The base price is the cotton fiber price in Mali in 2011. This price is obtained by dividing the real farm gate cotton seed price by the seed/lint coefficient ratio of 0.42. The elasticity of transmission is found by taking the average of the ratio between the percentage change in export price to the percentage change in the farm gate fiber price from 2004 to 2011 ($\% \Delta P_E / \% \Delta P_f$) (see Alston et al. 2007).

The second change in the government policy that will occur is the removal of the fertilizer subsidy. The subsidy on fertilizer has been provided since 2008. The goal was to increase agricultural productivity through moderate use of fertilizer, to improve soil fertility and to help farmers overcome the liquidity constraint. Although important in improving agricultural production, the fertilizer subsidy program will not be sustainable in a medium or long term because of several factors.

First of all, criticisms of the fertilizer program view this program as high cost for governments in developing countries (Harrigan 2008) and donors are unlikely to be willing to help pay for this program as costs accelerate with more farmer participation.

Second, evidence from Malawi shows that a voucher fertilizer subsidy program is often inefficient because of difficulties in the implementation of the program. In Malawi, there was a lack of transparency in targeting the desired beneficiaries of the fertilizer subsidy. Generally, producers with a significant number of assets or strong political connections receive the subsidy as opposed to poor farmers with little endowment and connections who are often claimed to be the main beneficiaries (Ricker-Gilbert et al. 2011).

Thirdly, the market prices for fertilizer in Mali are expected to stay on an upward trend. In 2011, fertilizer prices were moving toward the record level of the 2008 year after a setback in 2010 (see figure 5.1). From 2011 to 2014, world demand for fertilizer is expected to remain strong due to population growth, rising income in emerging countries and biofuel development in USA, Brazil and European Union.

The growing population and incomes in emerging countries are expected to increase the demand for vegetables, grains and other agricultural products as well as lead to intensification in land use with increasing application of fertilizer. Rising income will boost demand for meat which uses grains as animal feeds. The production of biofuels using cereals such as corn, sugar cane and oilseed is forecasted to increase and compete with the crude oil prices which are projected to remain strong (IFA 2011). All those factors accelerate grain consumption and support a rise in fertilizer demand.

On the supply side, world fertilizer is forecasted to increase at modest rates due to increased production capacity in many exporting countries (FAO 2010). This growth will be mainly triggered by surpluses of nitrogen and phosphate while potash is likely to remain more or less stable. Overall, even though the balance between supply and demand shows some positive surpluses in the medium term, it is expected to be tight in the coming years.

So, with the expansion of the fertilizer subsidy to more crops and more farmers and with the probable increased fertilizer prices, the fertilizer subsidy program will become more expensive for the Malian government and ultimately will not be fiscally sustainable for the government. Moreover, in the medium to long run if there are crises again international agencies will push the government to reduce or eliminate the fertilizer subsidies. Thus we will consider the case of eliminating the 24 percent difference between world and Malian fertilizer prices.

## 7.2 Effect of a Reduction in the Farm Gate Cotton Price

The 8 percent decrease in the farm gate price leads to a small decrease in the area in cotton and a marginal increase in maize area (table 7.2). Production of the new sorghum stays at its maximum 4 ha with the credit constraint.

The income effect resulting from the 8 percent reduction in the cotton price is a decrease of the household wealth by 5 percent (table 7.2). This is primarily due to the reduction in the expected return from cotton following a decline in cotton area. A larger reduction in household wealth has been offset by the higher returns to sorghum driven by the increased sorghum sales. This is an important result as marketing strategies to improve sorghum prices or in general grain prices can soften the negative impact on the household wealth following a decline in the farm gate cotton price. The reduction in cotton price introduces more risk in the distribution of the expected ending wealth through the larger standard deviation of wealth and increases substantially the marginal value of cash across periods (table 7.2).

The higher marginal value of the sorghum credit constraint of 1.48 (table 7.2) indicates farmers' willingness to invest more in the improved sorghum. Sorghum provides the largest expected return among the crops due to a combination of factors including the reduced cotton price, the fertilizer subsidy and the prospect to sell sorghum at higher prices after storage.

Purchases of grains particularly sorghum and maize are very limited during the post-harvest season (table 7.3). Rather farmers increase their sales of sorghum by selling a larger part of their sorghum production in the price recovery period while no harvest sales occur (table 7.3). Consumption of sorghum is kept at a minimal level due to the higher return on marketing. Maize and to a lesser extent millet, substitute for sorghum in consumption (table 7.2). Millet contributes to the financing of household expenditures at harvest. There is a higher percentage of millet sold at harvest time relatively to the other grains to compensate for the decreased cotton sold then (see table 7.3).

Table 7.2: Farmers' Response to a Reduction in Cotton Price and Removal of Fertilizer Subsidy

| Traditional Crop<br>Technologies | Base Case<br>Improved Sorghum Marketing Strategy for all Grains<br>2011 Economy | Scenario 1<br>Improved Sorghum<br>MS for all Grains<br>Reduction in Cotton Price only | Scenario 2<br>Improved Sorghum<br>MS for all Grains<br>Reduction in Cotton Price<br>and Removal of Fertilizer Subsidy |
|---|---|---|---|
| Cotton Price | 231 | 212 | 212 |
| Cotton Area (ha) | 3.49 | 3.31 | 1.35 |
| Percentage change | | -5% | -61% |
| Maize Area (ha) | 4.51 | 4.7 | 1.17 |
| Percentage change | | 4% | -74% |
| Traditional Sorghum Area (ha) | 0 | 0 | 6.47 |
| Percentage change | | | |
| Millet Area (ha) | 3 | 3 | 3 |
| New Sorghum | 4 | 4 | 3.01 |
| Percentage change | | 0% | -25% |
| Total Area (ha) | 15 | 15 | 15 |
| Expected End Wealth (F CFA) | 1,457,230 | 1,388,355 | 1,154,091 |
| Percentage change | | -5% | -21% |
| Marginal Value of the IST Credit Constraint | 1.28 | 1.48 | 0.80 |
| Minimum Wealth (CFA) | 72,088 | 19,952 | 0.000 |
| Maximum Wealth (CFA) | 4,271,996 | 4,261,232 | 4,489,907 |
| Standard Deviation of Wealth | 816,187 | 826,410 | 888,311 |
| Marginal Value of Grain Balance Constraint (CFA/kg) | | | |
| Maize | 21,728 | 21,775 | 24,823 |
| Millet | 27,096 | 27,142 | 27,994 |
| Sorghum | 26,117 | 26,120 | 26,222 |
| Max Marginal Value of Cash Period 2 | 1.69 | 1.70 | 2.36 |
| Max Marginal Value of Cash Period 3 | 1.36 | 1.39 | 12.82 |

Source: Model Results

Exchange rate: 1 $ US =452.61 F CFA on April 18, 2011 at www.oanda.com

Table 7.3: Expected Grain Consumption, Sales and Purchases across Policy Scenarios

| | Expected Consumption (kg) | | Expected Sales (kg) | | Expected Purchases (kg) | |
|---|---|---|---|---|---|---|
| | Harvest Season | Price Recovery Season | Harvest Season | Price Recovery Season | Harvest Season | Price Recovery Season |
| Improved Sorghum and Marketing Strategies | | | | | | |
| Sorghum | 205 | 280 | 0 | 2962 | 167 | 13 |
| Maize | 3435 | 2261 | 0 | 1419 | 396 | 1 |
| Millet | 5 | 375 | 287 | 907 | 0 | 22 |
| Total | 3645 | 2916 | 287 | 5289 | 562 | 36 |
| Reduction in Cotton Price only | | | | | | |
| Sorghum | 105 | 285 | 0 | 3081 | 71 | 6 |
| Maize | 3536 | 2269 | 1 | 1557 | 169 | 1 |
| Millet | 4 | 362 | 378 | 925 | 0 | 12 |
| Total | 3645 | 2916 | 378 | 5562 | 241 | 19 |
| Reduction in Cotton Prices and Removal of Fertilizer Subsidy | | | | | | |
| Sorghum | 2203 | 1601 | 0 | 4634 | 0 | 0 |
| Maize | 1442 | 781 | 0 | 147 | 330 | 180 |
| Millet | 0 | 533 | 738 | 836 | 0 | 7 |
| Total | 3645 | 2916 | 738 | 5617 | 330 | 187 |

Model Results

## 7.3. Effect of a Reduction in Cotton Price and Removal of Fertilizer Subsidy

With the reduction in cotton seed price combined with the increased fertilizer costs, there is a double constraint on the cotton and maize production. First, the lower cotton price reduces the cotton expected returns and the area planted to cotton (table 7.2). Secondly, the higher fertilizer costs further reduce cotton profitability and the acreage response. Maize area decreases also substantially (table 7.2) because the input tied credit available for maize as well is linked to the cotton price and the cost of fertilizer. Maize input credits from the CMDT must be repaid in cotton.

The improved sorghum area declines by 25 percent but the declines in cotton and maize area are at least twice that. The traditional sorghum area (without fertilizer) increases by a sizable amount and is now cropped on 6 ha of land. The grain marketing opportunity at higher prices improves the expected return of sorghum and reduces the effect of higher fertilizer costs on the improved sorghum profitability. Moreover, the production costs of the improved sorghum cultivar are lower than those of cotton and maize. Those two latter crops require higher level of fertilizer (200 kg/ha instead of 100 kg/ha for the improved sorghum) and other input expenses including a high level of insecticides for cotton.[19]

Profitability of sorghum increases with farmers' ability to take advantage of the price seasonality. The share of sorghum planted on the best lands increases from 33 percent to 75 percent and the use of sorghum as a cash crop is enhanced with higher sales at harvest and during the second price period (table 7.3). With the decrease in maize production and larger supply of sorghum, this latter crop substitutes for maize in consumption.

A change in the 2011 agricultural economy simulated through a decline in cotton price and the elimination of the fertilizer subsidy leads to a sharp reduction in household wealth, which falls by 21 percent (table 7.2). There is a higher exposure to risk in the distribution of wealth and in the poor states of nature where farmers do not make any profit, the marginal value of cash achieves a peak level (table 7.2). Clearly, the cost of fertilizer is a central policy measure which impacts markedly household wealth.

## 7.4 Summary

The predicted policy change of 8 percent reduction in the cotton seed price has only a small impact on the household wealth and cotton area. The yield effect of improved sorghum and the ability of farmers to store and sell sorghum after harvest play key roles in generating additional revenue if farmers continue to have access to bank loans at favorable interest rates as they do presently. This combination of factors could lead to major shifts in some regions such as the Koutiala region and the sorghum

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[19] The production function for cotton and maize includes farmers' customary use of fertilizer as recommended by CMDT and zero fertilization. The case is similar for sorghum but with lower fertilizer recommendations. In the future more alternative fertilization data would be useful for defining other alternatives as some of the reduction of maize and cotton may be due lack of alternative options, this linear production function. We are grateful to Jerry Shively for this point.

technology also should be a big benefit to Mali in feeding itself and in making shifts to more processed food from sorghum and to the use of sorghum substituting for maize in feed rations.

When the subsidy is removed on fertilizer, farmers' incomes are severely affected. But, there are still higher returns on cultivating the improved sorghum compared to cotton and maize. Sorghum profitability was boosted here by the returns on marketing. There were substantial impacts on marketing from the shifts to sorghum. This differs from our earlier finding that marketing had little impact on incomes in comparison with the sorghum technology introduction.

As the fertilizer subsidy will be fiscally unsustainable in the medium to long run, it is important to find other non-subsidized methods to reduce the cost of fertilizer. These could include higher nutrient fertilizers, better transportation, improved agronomy to make better use of available fertilizer, and improved distribution networks for fertilizer.After evaluating the importance of new technology, marketing and fertilizer in driving household incomes, the next question is the benefits to women (and children) from these different changes.

# CHAPTER 8: WELFARE IMPLICATIONS OF TECHNOLOGICAL CHANGE AND AGRICULTURAL POLICY ON WOMEN

This chapter raises the question of the benefits accruing to women and the welfare impact on women resulting from new economic opportunities already studied for their household income effects in the previous chapters. The specific economic opportunities are the new sorghum technologies and associated marketing practices, the increased cotton prices, and finally the fertilizer subsidy. In the previous chapter, we have observed that these latter economic opportunities led to substantial income effects for the household. In this chapter, we are emphasizing the sharing of the increased profit within the household, particularly women's gains from the improved technology and marketing.

Women are an important labor resource used on the household communal field along with the male adult family members. When a new economic opportunity requiring higher labor investments occurs, women have been observed reducing their participation on their individual plots to respond to the higher demand for labor on the communal or family land (Savadogo, Sanders and Mc Millan 1989). The resulting effect is an increase in the household income generated on the family plot with men controlling this increased income. The share of the additional income accruing to women or income compensation for women's increased labor is the outcome of negotiation between spouses and depends on their relative bargaining power. Since the household head has greater control of the household decision making and productive resources, women (and the other adult males in the household) may not be fully compensated for their increased labor participation on the communal field.

With many other demands on women's time for child care, food preparation, water and firewood delivery and the priority of work in the communal lands, greater labor demand on the communal lands means reduced time available and hence income from the private plots of women. So, this chapter aims at investigating the benefits and net welfare effects that women get from the adoption of new sorghum technologies and the higher cotton prices and the other changes discussed in the previous chapters.

First, it describes the household decision making and women's role in the farming system. Second, the methodology and results of the estimation of the impact of adoption of the new policies on women are discussed. Lastly, policy implications are derived from the findings.

## 8.1. Household Decision Making

This section considers the intra-family labor allocation and the role of women in the farm family system. It also defines the theories of resource allocation and income distribution within the household.

### 8.1.1. Farm Family and Women's Traditional Roles

In rural sub-Saharan African households, agricultural production generally takes place on a communal land area and in private, individual plots. The historic role of the communal land is to provide the subsistence consumption during the year. With the addition of cash crops, the household head obligation remains to provide for the family food requirements. However, there are often increased income streams beyond these basic food requirements. These are still controlled by the household[20] head with other household members including women increasingly contesting for them.

The male household head has a dominant power in his relationship with other household members. He controls the labor allocated to the communal field and the income generated from this land (Gladwin and McMillan 1989, Hopkins, Levin and

[20] The household in West Africa traditionally refers to large extended families composed of several nuclear families, generally siblings living together with their wives and children. The size may exceed 30 but the average is around 15. The household is under the authority of a single head, usually a man. Anthropologists often define the household as those eating from the same pot.

Haddad, 1994). All active household members can allocate their labor to their private plot activities only after meeting the obligation of working on the communal land.

Social and religious customs prevailing in a given household, as well as women's age dictate the extent of women involvement on the communal land. This varies from no work on the communal land to full employment. Indeed, even though some families exempt women from participating in communal activities, many other households require women to perform certain agricultural tasks during the farming season. Younger women are generally involved in most cropping activities whereas older women have a privileged status in the household. The participation of older women in the communal plot activities is voluntary. They are also exempted from most domestic household chores particularly when their daughters in law are included in the extended family and do these chores for them. But we are studying in this research the average woman in the household with obligation to work on the communal plot and who receives a private plot.

In return for labor participation on the communal plot, family subsistence grain consumption and other necessary household expenditures are paid for by the household head. Also, depending on the state of nature of the cropping year, women are compensated for their work during the agricultural season by receiving some gifts including clothes, cash payment or an additional share of the grain production above their subsistence needs, which they can sell. Private plots are allocated by male household heads to individual household members principally for the purpose of growing crops for sale to supply their personal needs or to complement consumption in the family. The rights to specific private plots are generally made on an annual basis based on the household head discretion and land availability.

Women produce vegetables, legumes and spices on their private plots. Women are the principal decision makers regarding production on their private plot or other personal income generating activities. Women use their private plots to complement home consumption and for their own financial needs and those of their children. They make decisions based on the residual time left after meeting the requirement for household chores and communal work. Then, depending on their time availability after these main activities including their private plot, they can be involved in off farm work or self-employment activities such as craft work, beer brewing or food marketing. Given all these multiple tasks performed by women, they have a very long work day and have to give up their leisure time (Lado 1992). Some studies reported that women spend on average 12-16 hours a day in agricultural and household work (Warner and Campbell 2000). While women contribute actively to farm production and family income generation, women and non-household head men are confronted with unequal access to productive resources including land, labor, technology, and credit (Warner and Campbell 2000).

The introduction of a new intensive agricultural technology on the communal plot involves a readjustment of women's labor allocation with increasing time spent on the communal plot. This leads to less labor supplied to the private plot and thereby to reduced earnings from the private plot. But women can still be made better off depending upon how the household head spends the increased incomes resulting from the new technologies and the decision making prevailing in the household.

### 8.1.2. Theories of Household Decision Making

Household decision making plays an important role in determining the distribution of income within the family and the payment received by women for their communal work. Three types of family decision making have been specified as influencing the value of women's labor. These are the exploitation theory, the neo-classical theory and bargaining theory.

In the exploitation theory the household head is portrayed as a dictator who allocates resources in the family not necessarily for the best interest of household members. Women are relegated to subordinate roles within the household. The division of labor and distribution of resources within the family is shaped to be more profitable to the male household head (Heath and Ciscel 1988). The household head reaps most of the benefits of the labor efforts of family members and women's share of household income is determined by whatever the household head wants to pay them. In this condition, the value of women's labor in farm production is not determined by economic market forces but rather enforced by social factors, customs or expectations about women's role in the family and economy (Folbre 1986). Under the exploitation theory, we would not expect women's share of household income to increase with new income streams in the household or to increase very much.

The other extreme representation of the decision making in the household is the one attributed to the neo-classical economists who represent the household as a unitary model with a joint utility function. The household head is described as being altruistic and allocates resources within the family for the best interest of family members. So incomes would be divided by the needs of the household and the household head only embodies this decision making maximizing the welfare of the household. In the altruistic decision making, increased income streams are perfectly divided satisfying everybody. Empirically, the joint utility hypothesis has been challenged by empirical studies. Much informal evidence in developing countries indicate that household members have diverse preferences, particularly in the context of extended family and household demand for goods and leisure depends on the identity of the individual controlling the income (see for example Schlutz 1990, Thomas 1997, and Hopkins et al. 1994).

Generally, the exploitation and neo-classical views of women's labor allocation and family decision making have not been empirically confirmed. Rather, numerous studies in developing countries point out some interactions in the process of household resource allocation and income distribution within the household. The dynamic of intra-household resource allocation is captured through game theory tools. For this aim, Nash Bargaining models of cooperation and non-cooperation in resource allocation and distribution within the family have been developed by Bourguignon and Chiappori (1992), Manser and Brown (1980) as well as Mc Elroy and Horney (1981).

The decision making process with the bargaining theory is analogous to the one of a firm where conflicts are resolved through negotiation. All household members know they need to collaborate to survive but there is conflict over the income streams especially as new technologies increase income. For example both company officials and the workers (or union) conflict over income shares but both know they are dependent upon each other. Sen (1990) terms this as "cooperation-conflict". Hence, bargaining theories have been developed based on the cooperation-conflict relationship in the household. The outcome of negotiation is determined by the relative bargaining power which is derived from the parties' best alternative options or "threat point". But, there is also possibility for the party with less power to exit the contract if dissatisfied. The relevance of the exit option between bargaining parties depends on how credible the threat point is. So, in bargaining models, a key determinant of women's share of household income is their bargaining power. Women's bargaining power is generally influenced by better education, women's opportunity costs, access to productive resources and social norms (Jones 1983a, Agarwal 1997).

## 8.2. Method for the Estimation Procedure for the Welfare Impact of Policies Changes on Women

The welfare effect on women of new policy initiatives will be measured through the change in women's total income in various scenarios with technology and policy changes that were analyzed in previous chapters. The conceptual approach, empirical estimation approach and the data required are laid out below.

### 8.2.1. Conceptual Approach

The conceptual approach of the welfare impact of new sorghum technologies and agricultural policies focuses on the two most important farm productive activities for women: the communal field and the private plot. Women's additional work on the communal plot resulting from the increased demand for their labor of new technologies and policies enables them to receive additional compensation at harvest and to guarantee their food consumption and that of their children. The private plot work is women's best alternative opportunity. The welfare impact of the introduction of a labor intensive new technologies and/or policies on the communal plot can be summarized in the diagram below:

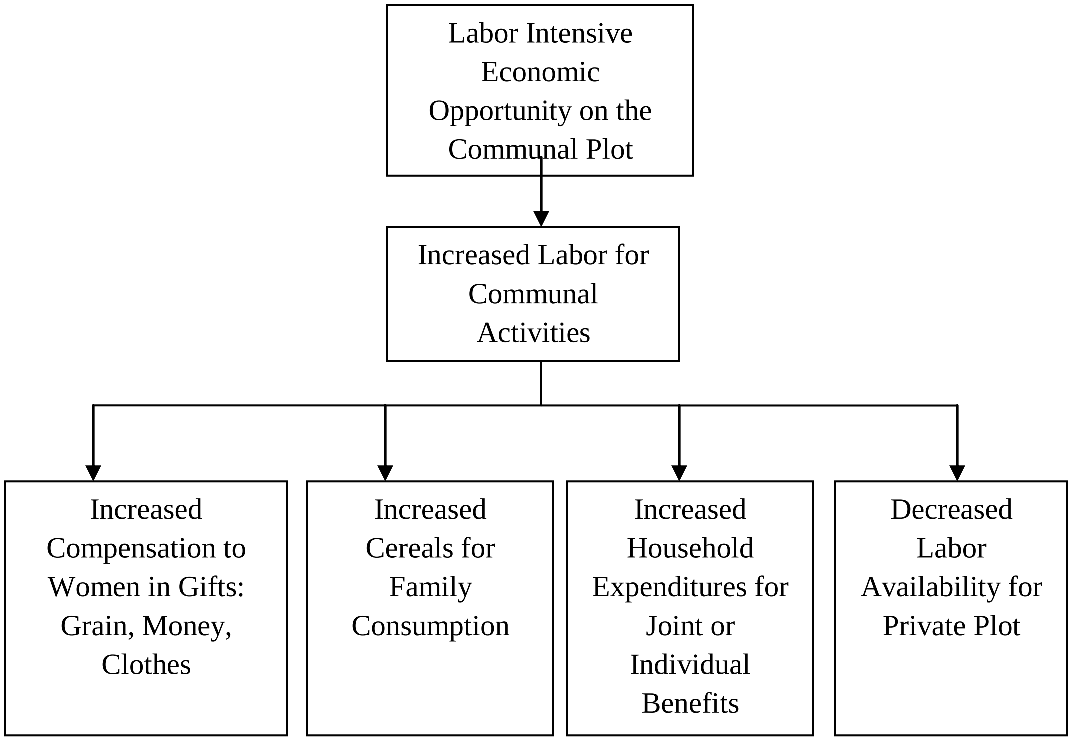


Figure 8.1: Diagram of the Welfare Impact on Women of a Labor Intensive Economic Opportunity

Source: Author Own Design

Conceptually, the introduction of new economic opportunity on the communal plot leads to a reallocation of labor to respond to the higher demand for labor on the communal plot and will result in an increased profit controlled by the household head. Then the change in women's welfare following the new economic opportunity will depend on women's share from the increased incomes and the impact that her labor use on the communal land will have on her private plot.[21]

The increased profit from the communal plot translates into increased payments from the communal plot in the form of gifts principally clothes, cash or cereals. In the 1990s, the cotton economy was characterized by higher cotton seed price and higher

[21] This increase labor could also come from other activities or leisure. We are treating here the case where the labor increase in the communal plot reduces private plot activity. There is a literature arguing that women have no leisure time as they have many pressing responsibilities.

profits for farm households. So, during this period of cotton boom the harvest gifts to women were substantial (Lilja and Sanders 1998). Cash and clothes were the principal gifts received. With the decline of the cotton economy in the 21st century, the system returned to a more traditional pattern. Women's harvest gifts were reduced and included mainly grains which women could sell. With the 2011 spike in the cotton price and adoption of new technologies, sizable income surplus for households are expected and women harvest gifts are therefore likely to increase.

The supply of labor time on the communal plot enables household members to receive their subsistence allowance. The household head has the obligation to provide the subsistence allowance to all his household members. The subsistence allowance is a minimum amount of grains consumed by every household member and it is the outcome of the production of cereals on the communal field. So, home consumption is part of the household members' compensation for their collective work on the family farm. In the traditional system, the pressure of just providing subsistence consumption leads to collaboration. When there is new technology, there will be increased demands for family labor and new income streams will be generated. In this new system of the cotton zone, farmers are already eating well. So little change in the subsistence grain production is expected[22].

With the increased returns on the communal plot, farmers have often been observed making household investments for the collective good of their families. The household investment expenditures benefiting women include housing improvement, new farm equipment, children's education, and health improvement. Even though such investments undoubtedly improve women's welfare, it is difficult to measure quantitatively the effect of many household investments on women's welfare. This is illustrated by asking how much a motorcycle purchase, housing improvement or another wife for the household head benefits women? An additional wife may reduce the labor requirements of other family members. Clearly, improvement in housing would benefit all household members but how much is the benefit to women? Given the limits to

[22] Other food components were undoubtedly added to the grain consumption but we did not measure them. So, we understate women's welfare improvement by the value of diet improvement.

measure the effect of such parameters on women's total income, they will not be included in the estimation of women's welfare.

Under the traditional technology, women receive most of their disposable income from the private plot although these are generally marginal lands in which few improved inputs are used. Income from self-employment activities is minimal in many regions[23] and the off-farm rural labor market has become more restricted with the downturn of the cotton economy before the year 2010.[24] With the increased labor time on the communal land, women's additional time will be principally coming from the private plot since household duties require a fixed amount of labor time and little time is allocated to non-farm activities during the agricultural season. Women are constrained to spend at least 4 hours/day in domestic work from field interviews. Self-employment opportunities are not very common during the agricultural season so the amount of time that women devote to these activities is minimal.

Thus the evaluation of the welfare impact on women of new policies will consider the benefits received from the communal field and the changes in the returns from the private plot.[25]

### 8.2.2. Empirical Estimation

The welfare impact on women of new economic incentives is evaluated by using a partial budgeting approach which considers changes in the communal payment, the subsistence allowance and the private plot earnings. The empirical estimation of the welfare impact of new sorghum technologies and agricultural policies focuses on the two most important productive activities for women: the communal field and the private plot. Women's additional work on the communal plot enables them to receive additional

[23] Villages on the main highways with seasonal products to sell often benefit women but this was not important in our evaluated village.

[24] We are restating that the year 2011 was characterized by a spike in the farm gate cotton price

[25] This approach underestimates surely women's welfare but it is the best that can be done given the limits in measuring quantitatively the benefits to women from increased family expenditures.

compensation at harvest and to guarantee their food consumption and that of their children. The private plot work is women's best alternative opportunity.
The general form of women's income earnings is defined as:

$$Y^f = f(y_c^f, y_p^f, y_s^f) \tag{8.1}$$

where $Y^f$ is the total private income earned by women, $y_c^f$ is the communal plot payment $y_s^f$ is the value of the subsistence allowance and $y_p^f$ is the private plot earnings. The communal payment is represented by the value of gifts that women receive at harvest from the household head for their labor effort supplied on the communal plot during the agricultural season. These gifts are received in diverse forms that are in-kind (grains, clothes) or in cash payment.

The welfare impact of technological change or new economic policy on women is a function of first the income gains received by women for their increased labor supply on the communal plot, second the expected increase in the subsistence allowance and third the expected income losses from the private plot due to the reduction in time spent on the private plot. It can be described as follows:

$$\frac{\Delta Y^f}{\Delta T} = f\left(\frac{\Delta y_c^f}{\Delta T}, \frac{\Delta y_p^f}{\Delta T}, \frac{\Delta y_s^f}{\Delta T}\right) \tag{8.2}$$

where $\Delta Y^f / \Delta T$ is the change in total income earned by women under the new policy scenario, ( $\Delta y_c^f / \Delta T$ ) is the change in women's compensations for their work on the communal, and ( $\Delta y_s^f / \Delta T$ ) are the changes in subsistence consumption and private plot earnings ( $\Delta y_p^f / \Delta T$ ), both relative to the household income changes.

The income gain from increased labor participation on the communal plot is identified as the share of household wealth that women receive under the new economic opportunity. During the field interviews, we estimated the proportion ( $\beta$ ) of household income that women were receiving at harvest under historic technological change (traditional technology and new agricultural technology or good crop year). This proportion is the ratio of the value of the gifts received by women at harvest over the total household income[26]. The increase in the proportion of household income granted to women when a new economic opportunity emerges reflects women's bargaining power within the household. We expect the proportion of increased household income that women receive to be non-zero and positive if the household decision making is characterized by bargaining or altruism, as opposed to an exploitative decision making.

The change in women's share of the household wealth following the adoption of a new policy ( $\Delta y_c^f / \Delta T$ ) is obtained by multiplying the change in women's share of household income relatively to their bargaining power ( $\Delta y_c^f / \Delta \beta$ ) by the change in women's proportion of household income from the traditional technologies to the new policies ( $\Delta \beta / \Delta T$ ). The mathematical expression is:

$$\frac{\Delta y_c^f}{\Delta T} = \frac{\Delta y_c^f}{\Delta \beta} * \frac{\Delta \beta}{\Delta T} \tag{8.3}$$

To estimate the income losses from the private plot, we assumed that the amount of labor withdrawn from the private plot corresponds exactly to the same amount of additional labor supplied to the communal land. Because of the lack of leisure time, women have to reallocate their labor instead of reducing their leisure time. So, there is a one to one relationship between the labor allocated to the communal and private plots.

$$-\Delta L_p = +\Delta L_c \tag{8.4}$$

The evaluation of women's labor contribution for each technology or policy scenario is derived directly from the farm programming results. Then, this estimate of women's time spent on the communal plot is equivalent to their reduced time on the private plot.

The resulting income losses from the private plot is found by multiplying the reduced labor time supplied to the private plot under each economic opportunity by the average return to the private plot.

$$\frac{\Delta y_p^f}{\Delta T} = \frac{\Delta l_p^f}{\Delta T} \left( \frac{y_p^f}{l_p^f} \right) \tag{8.5}$$

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[26] Given the difficulty that farmers have to reveal their income, we used the household expenditures as a proxy for household income. Total household expenditures have been reported in table 2.6 of chapter 2.

where $\Delta l_p^f / \Delta T$ is the variation in women's labor allocated to the private plot from the traditional technology to the new policy. $y_p^f / l_p^f$ is the total output on the private plot per unit of women's labor and corresponds to the average product of labor on the private plot with the traditional technology. In this study, the relevant range of women's production function is assumed to be linear. This is because field evidence (Coulibaly et al. 2011) revealed that women have access to very small areas of land (1/10 ha to 1 ha) and when they get additional improved inputs their productivity increases substantially even at a higher rate than those of men.[27]

The change in the subsistence allowance ($\Delta y_s^f / \Delta T$) is the difference in women's grain consumption before and after the policy interventions.

Our methodological procedure was inspired by Lilja and Sanders (1998) but it departs from this latter study in the way we estimated women's communal payment ($\Delta y_c^f / \Delta T$). The latter authors used an econometric model to find the coefficient estimate of the change in women's communal wage due to technological change. In our procedure, we used directly the results of the farm programming model and household survey to evaluate the changes in communal income led by technological innovation and new economic policy. Women's communal payment was the result of the product of the proportion of household income women declared receiving during the field survey and the value of the household wealth derived from the model results under each economic opportunity.

### 8.2.3 Data

Data used for this analysis were obtained from a random sample of 30 women from rural households that adopted sorghum new technologies respectively in the village of Garasso of the study area Koutiala. These women were the wives of the household

[27] We expect a sharply rising production function for women so these linear estimates would underestimate the potential gains to increased labor supply of women if other inputs were also available.

heads interviewed for the farm household model development in earlier chapters. One woman was surveyed randomly per household.

Evaluation of the welfare impacts of the new policies on women is based on the examination of women's conditions without and with the economic opportunity from sorghum technologies and the increased price for cotton. Respondents were interviewed about their labor contribution on communal plots, private plots, off farm, gifts they receive from the household head at harvest, private plot productions and sales, earnings from self-employment activities, bargaining ability over increased profits from the communal plot, livestock assets, and other social characteristics. Moreover, each interviewee was given the opportunity to discuss the effects that the new policy had on the time spent on the communal plot, private plot, self-employment activities, and leisure.

The data will be used to discuss women's labor allocation across productive and non-market activities, their income estimates and to analyze the net welfare impact of policy change on women.

## 8.3. Results of the Empirical Estimation of Women's Welfare

### Women's Welfare with Marketing Innovations and in the 2011 Economic Environment

Before delivering the results of the empirical estimation of the welfare impact on women of the technology change and the new cotton policy, we will discuss women's labor allocation and personal earnings in the study area.

### 8.3.1. Women Labor Allocation

The descriptive data analysis revealed that women allocate their labor across multiple simultaneous activities including farm work, non-farm activities and household duties.

Farming labor allocation includes the work on the communal plot and on own managed private plots. The activities on the communal plot take priority over the work on the personal plots. Married women work during few labor periods and shorter hours than men on the communal plot. Their labor input is only compulsory during planting, harvest labor periods including threshing and sometimes fertilizer application. Nonetheless, the household head is free to request additional labor input at any time if there is need for more labor supply such as during weeding activities. Data collected during the field survey and confirmed in Coulibaly et al. (1998) reveal that women spend on average six (6) hours per day working on the communal field whereas men usually work 8 hours.

Women have access to personal plots through their marital status and the head of the household. These plots are specified on an annual basis by the household head and their size and land quality depend on several factors with the most important being land availability and the social status of women in the household. In the sample of women interviewed, not all women had access to a private plot since land is a scarce resource. In the sample 73 % of the women had access to a private plot. In families with limited land resources to meet household food consumption, no private plots were granted to women. Older women in the household, who are retired cooking wives,[28] have priority in access to private plots over younger active cooking wives. Hence, the data reveal that the average age of women having access to a private plot is 47 whereas those who do not have access to a private plot are on average 37 years old. The average area of land cultivated by women with a private plot in the sample is 0.56 ha.

In Garasso, women with private plots usually grow crops that do not compete with the communal land's production. Women grow a variety of crops such as rice, okra, peanuts, soybeans and spices that are complementary to the household communal crop production. The yields of these crops are poor, less than 500 kg/ha for each crop because women face many constraints in farming. These constraints include poor soil fertility, and the lack of access to agricultural inputs such as organic and inorganic fertilizer, labor and plowing equipment. Women's fields are often depleted lands found on the edge of the

[28] Retired cooking wives in the household are women who no longer participate in the household chores and are not obligated to work on the communal plot during the agricultural season. A woman achieves this social status when at least one of her sons get married and brings his wife to live with the extended family in the compound. Her daughter in law represents an additional worker in the household. This latter then substitutes for her mother's in-law labor with respect to household duties and the labor obligation on the communal plot.

communal fields. Any attempt to increase women's private plot especially in the south might take into account land availability since in some southern villages land is constrained by population growth.

Access to input for the private plot is very restricted. The private plot production technology depends basically on women's own labor input. Women can work on their private plot after the communal work has been performed. Family labor specifically children's labor are made available to them once the activities on the communal fields are completed. They recruit their children and use their labor and other female's labor primarily during the peak labor season of weeding and harvesting. Women lack access to agricultural equipment and purchased inputs (fertilizer, herbicide). The limited access to productive resources and the time constraint facing female farmers clearly translates into many delays in their work and results in low productivity on their private fields. Also, during the labor demanding seasons for women on the communal plot (planting, fertilizer application and harvesting), activities on the private plots are often delayed or omitted. On average, women spend 2.8 hours per day working on the private plot, and the number of days that a woman will spend to work on one hectare of private land is 4 days for land preparation, 11 days for seeding, 24 days for weeding and 22 days for harvesting (see table 8.1).

Table 8.1: Women's Labor Allocation across Communal Plot and Private Plot

| | Communal Plot (days/ha) | Private Plot (days/ha) |
|---|---|---|
| Land Preparation | 4 | 4 |
| Seeding | 12 | 11 |
| Fertilizer Application | 2 | 0 |
| Thinning and weedings | 46 | 24 |
| Ridging | 19 | 0 |
| Harvest (& Threshing) | 133 | 22 |
| Total | 108 | 61 |

Source: Household Survey
Note: Women have less than one hectare of land.

Women non-farm activities are small commerce performed locally during weekly village market days or every day at home by children or older women, who are not involved in domestic duties and farming activities. Women, who do not have access to a private plot, have more time to engage in small retailing activities. Small commerce consists of sales of processed food, spices and the sales of tree crop products such as shea nuts, shea butter, bananas, mangoes and some other wild fruits. Women have less opportunity to expand their non-farm work during the rainy season as opposed to the dry season when there is less demand for agricultural activities. They do not generally engage in the non-farm activities during the peak agricultural labor seasons. The prospect for women to find off-farm employment is limited by the village remoteness of Garasso (55 km from the main town with poor roads most of the way), the lack of women's education and the inability to speak the language[29] used for commercial transactions. Moreover, domestic duties constrain women's ability to participate in off-farm activities.

Women's main family responsibility is to be in charge of the unpaid household chores. The household duties include cooking meals, hauling water, processing grains for domestic consumption, taking care of children, doing dishes, and fetching wood. These

[29] In the village of Garasso, women speak only the local language Minianka from their ethnic tribe as opposed to men who are able to speak at least two languages Minianka and Bambara, which is the national language in Mali and is used prominently in commercial transactions.

tasks involve a large amount of women's labor because they are labor intensive. In the data sample, active cooking wives spend at least 4 hours per day to perform their household duties. Grain processing, cooking and hauling water are the most time consuming household duties quoted by women during the informal interviews. For example, field observations showed that women can spend 2 hours per day processing grains which involves several steps including threshing the grains, blowing, cleaning and pounding the grains with a mortar and a pestle. In extended families meal cooking responsibilities rotate among married women. The wife in charge of cooking prepares breakfast for household members and then cooks lunch to be carried into the field for the workers. Once she is on the communal field, she might spend some time helping the other workers, and afterwards heads for her private field to finally go back home at the sun set (6:30 pm) to resume her work on the household chores. In the village surveyed, no labor saving household technologies such as grain mills, fuel efficient stoves or improved water pumps are available to enhance women's productivity and efficiency in accomplishing the household duties.

### 8.3.2 Women's Earnings

Women have diversified sources of income distributed across private plot and non-private plot owners (see table 8.2). These are sales of the private plot produce, non-farm activities, communal field incentives and women's work group activities. These activities generate some small amount of money used by women to finance their own needs, those of their children and consumption goods for the household.

Table 8.2: Income Earning Activities and Labor Allocation across the Main Activities

| Activities | Private Plot Owners | | | Non Private Plot Owners | | |
|---|---|---|---|---|---|---|
| | Return F CFA/day | Number days/year | Total Income F CFA | Return F CFA/day | Number days/year | Total Income F CFA |
| Private Plot | 1,042 ($2) | 35 | 36,461 ($81) | 0 | 0 | 0 |
| Off Farm | 431 ($1) | 20 | 8,617 ($19) | 952 ($2) | 43 | 40,813 ($90) |
| Work Group | 275 (<$1) | 4.0 | 1,087 ($2) | 419 ($1) | 3.3 | 1,363 ($3) |
| Livestock Fattening | 137 (<$1) | 168 | 22,977 ($51) | | | |
| Communal Plot | 25 (<$1) | 108 | 2,667 ($6) | 8 (<1$) | 108 | 900 ($2) |
| Total | 2,594 ($6) | 195 | 71,809 ($159) | 1,380 ($3) | 154 | 43,075 ($95) |

Source: Household Survey Data
Sample: 30 women with 73 percent having a private plot.
Exchange rate: 1 $ US =452.61 F CFA on April 18, 2011 at www.oanda.com

From the survey results, income from the private plot producers is the most important cash generating activity for women despite the low productivity of these plots. Data reveal that the value of their production on the 0.56 ha of land cultivated area is on average 36,461 F CFA ($US 80.56) which corresponds to 64,429 F CFA/ha ($US/ha 142.35). With the private plot savings, women generally invest in small ruminants (goats and sheeps) fattening activity. Hence, the small ruminants represent live assets for women and are important stock of wealth as revealed by the value reported in table 8.2. The third source of income generating activity for the private plot owners is the non-farm revenue with an average of 8,617 F CFA ($US 19) earned during the cropping season. Despite the limited amount of time invested in this non-farm activity, for women without access to a private plot, the returns are even higher than those earned from the communal field. For the non-private plot producers, non-farm work (petty commerce) is their main source of cash generating activities.

Compensation from the communal plot is the fourth largest income source for private plot producers and the second for the non-private plot owners. Under the traditional technology, payments to women for the communal work are low. The average payment for the communal work is estimated at 2,667 F CFA ($US 5.89) that is 178 FCFA/ha ($US/ha 0.39) for the private plot owners. The non-private plot owners receive as communal payments 900 F CFA ($US 2) or 60 F CFA/ha ($US/ha 0.13). So, private plot producers receive on average higher incomes than the non-private plot owners. This probably results from the larger opportunity costs[30] that private plot owners possess. Indeed, the earnings from the private plot represent these women's best alternative opportunity and apparently give them higher bargaining power over the sharing of the household wealth even though the household head entirely controls the allocation of the private plot to women annually.

In terms of average return, compensation from the communal plot leads to the lowest return on labor. It would not have been rational for a woman to allocate a substantial amount of time to the communal plot if it were not for the need to provide for the household subsistence allowance and living expenses. Economic rationality implies that women allocate labor across activities until their returns are equalized. Women's compensation for the communal work is lower than the daily wage for hiring labor estimated at 500 F CFA/day ($US/day 1.10). So, the household head will exploit this comparative advantage by mobilizing family labor for the communal work.

The payments for communal labor or bonuses are variable across years and depend upon the states of nature. For bad weather years there is little payment for the communal labor. During good years of crop production, these payments can be up to 77 percent higher than the value for normal years (unpublished field interview data).

The last source of women's income is the earnings from the gender workgroup. Men and women participate in gender farm work teams. In Garasso, 63 percent of women interviewed are members of a farm work team. The initial purpose of these work teams

[30] Otherwise, we would expect women not having access to private plots to receive more compensation from the communal plots because access to the private plots could be considered as a compensation for working on the communal plots.

was to assist the husbands of group members in performing agricultural tasks during peak labor seasons. These work groups used to function under a form of labor exchange with no or minimum income compensation for service rendered. The cash earned was spent in organizing some social activities and village parties (purchase of uniformed clothes for wedding, funerals, naming ceremonies, musical entertainment). But as already reported by Lilja and Sanders (1996), there is now evidence of institutional change in the functioning of women work teams. These groups are moving from mutual assistance and community service to be more profit oriented. They are hired by farmers for some agricultural tasks and with their collective bargaining power, the gender work groups demand to be paid generally on a fixed cash rate upon completion of their work or at harvest. Furthermore, these groups are evolving into associations and help members getting small loans for private investments instead of using the returns on their labor for community actions.

The total average income gains show a greater advantage to those with access to the private plots.

### 8.3.3. The Welfare Impact of the New Technologies and Policy Changes for Women Private Plot Producers

This section discusses the welfare impact on women private plot producers. The outline that is used to estimate the welfare impact of the new sorghum-marketing technology and the policy changes is detailed as follows.

First, we estimated women's communal gains under the traditional system and compare it with the new alternatives including the new sorghum-marketing package and policy changes. This was obtained by multiplying the proportion of household income received by women under each opportunity by the corresponding household wealth derived from the model results. From the household surveys, a woman's proportion of household income is estimated on average at 0.4 percent of the household income under the traditional technologies. This proportion is the value of the gifts (grains, clothes and cash) women declared receiving at harvest divided by the total household expenditures in the traditional system (544,978 F CFA or $1,204) as reported in table 2.6 in chapter 2. Under a new economic opportunity, this proportion increases to the average of 1.4 percent. This percentage is found by dividing the value of gifts women reported receiving during a good crop year or under the adoption of the new sorghum technology by the household expenditures defined in table 2.6.

Second, we estimated the resulting private plot earnings women receive under the new sorghum-marketing technology and the policy changes. The private plot earnings is the result of the average return to labor multiplied by the change in labor time from the traditional system to the new technology or policy environment. For the change in labor allocated to the private plot, we assumed that a unit of labor increased on the communal land is equivalent to the same unit of labor reduced from the private plot. This is because as already said earlier, the labor time allocated to the household chores is inelastic and women have virtually no leisure time (Warner and Campbell 2000).

Finally, women's total income across the traditional system and each of the new economic opportunities is defined as the sum of the communal income and the private plot earnings when obviously they could have benefit from other household expenditures. The welfare impact on women of the new technologies and policy change is defined as the percentage change in women's total income from the traditional system to the superior economic opportunity.

The evaluation of women's welfare is performed under the various policy initiatives analyzed in the preceding chapters. The base case consists in evaluating women's welfare with the traditional technologies and economic conditions prevailing when the primary data were collected. The economic conditions were represented by the announced cotton price of 200 F CFA/kg and no fertilizer subsidy. Then, the second scenario estimates women's welfare with the traditional technologies, adoption of marketing strategy and the 2011 agricultural policy. This latter policy reflects the substantial rise in cotton price of 31 percent and the 24 percent fertilizer subsidy. The marketing strategy is the sales of grains at higher prices in the second price period. The third scenario reflects the introduction of new sorghum technology accompanied by the marketing strategy and the 2011 agricultural economy. In the last scenario, women's welfare is estimated under the improved sorghum technology and marketing strategy but with the reduction in the cotton price and the elimination of the fertilizer subsidy (table 8.3).

Women's Welfare with Traditional Technologies

The use of traditional technologies yields a very low women's share of household wealth, estimated at 3,300 F CFA ($US 6.63). This is as expected since the use of traditional technologies doesn't generate much income surplus. Also, with the downturn of the cotton economy, household decision making has shifted back to the one prevailing in the subsistence system. During the time of cotton prosperity and the availability of significant market surplus, women as well as other household members received higher payments in gifts for their work on the communal plot. When they were not satisfied with their payments, women engaged in bargaining with the household head (Lilja and Sanders 1998). The share of the new income streams received was a function of their bargaining power. However, with the declining cotton seed price up to the year 2011, the returns to cotton have substantially declined and so did the communal payments to women.

So, in this traditional system, the main benefit to women for working on the communal land is the subsistence consumption and any household investment made for the benefit of the entire family including women. The model results estimate the yearly grain consumption per household member at 432 kg which is valued at 36,132 F CFA (US$ 79.83) (table 8.3). Compared to the gifts received at harvest, the value of the subsistence allowance is substantially larger and helps explain why in spite of the low communal payments, women keep supplying their labor to the communal field. Their goal is to guarantee enough food consumption for themselves and the other household members including children.

As expected, the private plot earnings represent women's main source of income in the traditional system. The total return to labor and land (0.56 ha) is estimated at 36,461 F CFA (US$ 80.56) (table 8.3). Thus, women's total income from farm work in the traditional system depends principally on the total return on land and labor of the private plot. An increase in the private plot total return will be made possible either by an increase in the time spent on it, a higher productivity or an increase in the amount of private land cultivated.

Table 8.3: Welfare Impact on Women of the Cotton Price Policy and Adoption of Improved Sorghum Technology

| | Traditional Technologies | Traditional Technology+ MS and 2011 Economy | IST MS 2011 Economy | IST+MS Reduction in Cotton Price, Removal of Fertilizer Subsidy |
|---|---|---|---|---|
| Household Wealth (FCFA) | 808,386 | 1,247,780 | 1,457,000 | 1,154,091 |
| | ($1,786) | ($2,757) | ($3,220) | ($2,550) |
| A Woman' Portion of Household Income | 0.4% | 1.4% | 1.4% | 1.4% |
| Women's Gains of Household Income (FCFA) | 3,257 | 17,976 | 20,994 | 16,627 |
| | ($7.20) | ($39.72) | ($46.38) | ($36.74) |
| Change in Communal Labor | | 38% | 26% | -10% |
| Grain Consumption (kg) | 432 | 432 | 432 | 432 |
| Value Consumption (FCFA) | 36,132 | 36,132 | 36,132 | 36,132 |
| | ($ 79.83) | ($79.83) | ($ 79.83) | ($79.83) |
| Average Return to Private Plot (0.56 ha) (F CFA) | 1,042 | 1,042 | 1,042 | 1,042 |
| | ($2.30) | ($2.30) | ($2.30) | ($2.30) |
| Number of days in private plot | 35 | 22 | 26 | 39 |
| Women Income from Private Plot (F CFA) | 36,461 | 22,606 | 26,981 | 40,107 |
| | ($80.56) | ($49.95) | ($59.61) | ($88.61) |
| Private Plot Income Gain or Loss (F CFA) | | -13,855 | -9,480 | 3,646 |
| | | (-$30.61) | (-$20.94) | (-$8.06) |
| Total Income per year (F CFA) | 39,717 | 40,582 | 47,975 | 56,733 |
| | ($88) | ($89.66) | ($106) | ($125.34) |
| Change in Total Income | | 2% | 21% | 43% |

Source: Author’s Calculations. Note: IST refers to improved sorghum technologies (high yielding sorghum cultivar, fertilizer use, and improved agronomic practices). MS refers to marketing strategies for all grains. We are not adding the value of grain consumption as it is constant across alternatives

Women's Welfare with Marketing Innovations and in the 2011 Economic Environment

With the implementation of the 2011 agricultural policies and farmers' ability to sell grains later in the year, the household wealth increases by 54 percent over the traditional case. This is because of the higher use of inputs including family labor. The model's outcome reports that family labor demand increased by 38 percent. At higher cotton prices and with access to fertilizer subsidy, cotton and maize productions increase considerably.

The household income gives the women a share of 17,976 F CFA that is 1,198 F C FA/ha ($US/ha 2.65). This is almost six times higher than the compensation paid to women with the traditional technologies (table 8.3). Although women receive a higher share of the communal income from the increased wealth, this share is still low compared to the increased profit generated by the spike in the cotton price, the use of fertilizer subsidy and the implementation of the marketing innovations. The remaining surplus not paid to family members is kept by the household head who might use it for its own preferences and/or to purchase some investment goods to enhance the well-being of the household. In this latter case, women will have additional gains for their communal work if the increased profit translates in an increased demand of the household goods for their benefits. The literature reports higher men's expenditures on cigarettes and alcohol (Warner and Campbell 2000) but these still represent a very small income quantity. Even if redirected, this income increase is minimal and would not affect the welfare of women and children significantly.

The increased demand for women's labor in the communal plot comes at the expenses of women's time on the private plot. Hence, women's labor on the private plot decreases by 38 percent and they spend 22 days instead of 35 days in their private plots for the traditional system without sorghum marketing strategy. This reduction of labor results in a loss of 13,855 F CFA ($US 30.61) in the returns from the private plot (table 8.3).

Since women's gains from the increased household income are higher than the decrease in their private plot earnings, women are still better off with a 2 percent increase in their total income (table 8.3).

Women's Welfare with the Improved Sorghum Technology and New Marketing Strategy in the 2011 Economic Conditions

Combining the adoption of improved sorghum along with the marketing strategy, plus the substantial increase in cotton price and the fertilizer subsidy, the household wealth increases by 80 percent relatively to the traditional system. There is an increase of 26 percent in women's labor requirements for the communal land, but this rise in women's labor time is less than that obtained in the system without the new technology. This is because of the decrease in labor requirements for the reduced area of cotton and maize.

The labor supplied to the communal work boosts the household income and translates into higher payments for women estimated at 20,994 F CFA (US$ 46.38) (table 8.3). With the proportion of woman's share of income being maintained at 1.4 percent, most of the increased income is controlled by the household head. The labor for the communal plot comes from the effort on the private plot through a reduction of 9 days spent on the private plot and a loss of 9,480 F CFA (US$ 20.94) in the total return of the private plot.

Despite the reduced returns from the private plot, the overall gains to women occur with an increase of 21 percent in their income (table 8.3). This positive income gain for women is due to the increased share of the household gains that compensates for the reduction in the private plot income.

Women's Welfare with the Improved Sorghum Technology and Marketing Strategy but removing the Fertilizer Subsidy and the Cotton Price Spike

The removal of the fertilizer subsidy and the reduction in cotton price increase the production costs of all intensive crops. The household wealth increases by only 43 percent which is the lowest income effect compared to the preceding economic opportunities (table 8.3).

Labor is pulled mainly out of cotton and maize production and allocated into traditional sorghum which is less labor demanding. The resulting effect is a release of 10 percent of family labor compared to the 2008 case. Women reinvest this released labor time in their best alternative opportunity, the private plot. Therefore, the private plot return increases by 3,646 F CFA ($US 8.06). The resulting effect in women's welfare is an increase of their income by 43 percent (table 8.3).

Notice that the change in the cotton pricing and fertilizer policies leads to the lowest household income effect on the household but provides the largest benefit for women because of the release of their labor and the consequent increase in the private plot returns. This highlights the existence of conflicting interest over resource allocation within the household and in response to the economic opportunities. The household head needs higher labor time from women to increase production on the communal plot and reaps higher profits. But women's productive priority is on the private plot because more labor time spent on the private plot leads to higher returns and increases her private earnings.

## 8.4. Summary

In the household economy, household members are obligated to allocate significant labor input on the communal plot for the family subsistence needs. The work on the communal plot is the most time consuming women's activities after the household chores but women earn little income relative to their other principal opportunity, i.e. the private plot. There was also potential from off-farm income for increasing women's income but again there were time constraints.

In terms of intra-household income distribution, women benefit relatively from the new economic opportunities introduced on the communal plot. The most profitable policy initiative for the household is the adoption of improved sorghum along with marketing strategies and the government interventions to raise the cotton price as well as to subsidize fertilizer. Nevertheless, these combined activities lead to lower welfare gains for women as compared to the elimination of the fertilizer subsidy and the lower cotton price.

The reason is that these economic opportunities from the higher cotton price and lower fertilizer price increase significantly the demand for female labor on the communal plot. On the other hand, the elimination of fertilizer subsidy and the lower cotton price release women's time from the communal plot. Labor is reallocated on the private plot and results in an increase of the total return on labor.

Thus, welfare enhancing policies for the household have a relatively low distributional impact on women. Women gain significantly from the increasing time allocated to the private plot. So, successful policies to increase women's welfare might be more concerned with releasing women's time constraints and increasing the returns on the private plot.

In regard to the household decision making process, the increase in the share of household income received by women with the adoption of new sorghum technologies and policy changes indicates some extent of cooperation in the household but it is a weak evidence of bargaining. Probably over time with more agricultural innovations and the increase in women's opportunity costs through off-farm work and gender work groups, women's bargaining power will increase.

## 8.5. Policy Suggestions

This research has shown that the increase in women's welfare will occur through the release of their time from their most demanding labor activities and the investment of their time in the opportunity that maximizes their private income. In this study, women's private plot is found to be their most rewarding economic activity. Therefore, welfare enhancing policies for women could focus on releasing time from the less economic profitable activities and increasing returns on the private plot as also recommended by many gender related literatures.

A rise in the private plot returns will follow an increase in the private plot productivity. This could be led by women's access to good lands, adoption of yield increasing technologies such as chemical fertilizer and high yielding cultivars on women's plots. But in the current socio-economic context, the productive resources are under male control and there is very limited opportunity to increase women's access to those required agricultural inputs. Also, even if access to quality land and inputs become effective, another bottleneck resides in women's control of the improved private plot outputs. Indeed, several projects have failed to achieve their expected results on women because the women did not control the output resulting from the introduction of the agricultural technologies on the private plots (Dolan 2001).

Greater control of women's output can be achieved from strengthening their negotiation power, for example through the gender groups. In the Mopti region of Mali, the IER-INTSORMIL program has been successful at helping women to benefit from the new millet technologies by convincing their husbands to allow women to have access to a portion of the lands. Women work individually but create marketing groups to share the productivity gains.

An alternative to the concentration on the private plot is to raise the compensations received from the family plot. The share of profit received from the communal plot under traditional technologies and new economic opportunities are very low relatively to the amount of time women spend for the communal work. The remaining income is concentrated with the household head who uses it for his individual preferences and family needs. Although women benefit from the household expenditures, higher cash payments will develop greater incentive to increase labor productivity on the communal plot and may result in larger profit for the household.  In other regions this concentration of income for the household head and poor compensation for other family members is one of the factors leading to the breakup of the large households into nuclear families (Lilja and Sanders 1998).

A second alternative to increase women's income is the release of women's time from the labor intensive farm activities and unpaid household chores. The release of time from the labor intensive farm activities will be made possible with diffusion of agricultural technologies that require less investment in labor such as cereal technologies.

Concerning the unpaid domestic activities, the inelastic sizable amount of time that women spend for the domestic work is a great obstacle to the development of economic employment opportunities for women. The duty of fetching water, firewood, and traditional processing of grains for meals all consume tremendous amount of time. So, household labor saving technologies including motorized water pumps, improved stoves and grain mills are expected to be effective in relieving women from the domestic work burden and create opportunities for productive activities. Lawrence et al. (2001)

have demonstrated that in Burkina Faso, the improved stoves were very efficient in releasing women's time from the household chores and increasing their welfare.

Additional free time will enable women to engage in non-farming activities where they can have extra source of cash. Petty commerce has been identified as a profitable earning activity for women although few opportunities exist currently to increase the market share for this activity given the limited market size in the study area and the distance from the paved highway. However, with further technology adoption and overall regional economic growth there will be potential to increase market size and increase demand for women's retailing products.

# CHAPTER 9: CONCLUSION AND POLICY IMPLICATIONS

Mali has experienced significant increases in area and productivity of the main cereal crops over the past ten years. While the cereal sector has been gaining in yields, the cotton sector, which has been the backbone of the Malian agricultural economy and the main source of cash income for farmers has been through a period of drastic decline for the last decade excluding the temporary upswing in price in 2010. There is now evidence that an agricultural diversification strategy is needed to sustain farmers' income and help them to cope with the declining prices in the world cotton market.

Hence, questions are raised about the choice of investment strategies between restoring the cotton sector and/or diversifying into the cereals that can be most successful in enhancing farmers' income. Though past policy initiatives have put a greater emphasis on improving maize productivity, sorghum offers a stronger comparative advantage to maize outside the high rainfall areas. Sorghum tolerates better flood, drought and soil nutrient deficiencies than maize. So, sorghum can help farm households secure enough food for consumption and can represent a source of cash income.

Various policy instruments have been introduced at the farm level to support the development of the sorghum sector, promote food security and revamp the cotton economy. These policy instruments include sorghum agricultural technologies, sorghum marketing strategies, cotton pricing policy and a fertilizer subsidy extended to sorghum and millet in 2011. The evaluation of the farm level impact and the distributional effects within the household of those policy initiatives is essential to provide decision makers with specific information with the potential to promote agricultural growth and enhance farmers' livelihoods. Hence, this research provides estimates of the income effects of improved sorghum technology with and without marketing change. It also focuses on one of the main innovations of the early 21st century in many developing countries, the fertilizer subsidies. This study also derives the welfare implications for women of the above policy initiatives.

In Mali, recent agricultural policies to restore the cotton sector were based on a sizable increase in the farm gate cotton price and a fertilizer subsidy. The model estimation of the impact of the cotton pricing policy of a 31 percent increase in cotton price and 24 percent fertilizer subsidy indicates a substantial impact of those policies on the cotton sector as the cotton area and the farm household income increased considerably. These findings indicate that the cotton pricing policy and fertilizer subsidy program are important policies to be considered to increase farmers' incomes and for a recovery of the cotton industry. The Malian government has been dependent upon the earnings of cotton and these have been decreased recently.[31]

In the objective of providing alternative source of income for farmers and raising traditional sorghum productivity, we evaluated the effects of the introduction of sorghum agricultural technologies with the present access to the fertilizer subsidy and marketing strategies. The model results reveal that the improved sorghum technology is rapidly adopted. Farm household income increases by 20 percent. Most of this income effect is triggered by the yield effect led by the sorghum technology (improved cultivar, moderate inorganic fertilizer and improved agronomy). There is only a small additional effect from the improved marketing practices.

These results indicate that the improved sorghum technology is a viable source of revenue diversification when farmers have access to improved cultivars, fertilizers, and input credit. The farmers' associations facilitate all these things. Storage and late selling will ultimately lead to lower prices as more farmers embrace these strategies. Then other marketing activities will need to progress to include new markets such as the use of sorghum in poultry feed substituting for maize. Meanwhile, a focus on rapid technology expansion appears to have higher returns than the storage investments for the improved marketing.

[31] In recent years, gold has been replacing cotton as the principal source of foreign exchange and Mali has been promoting diversification in the cotton zone, especially increases in financing of inputs for maize.

The cotton prices of 2011 were very high and were largely affected by climatic events in China. With the continuing introduction of Bt cotton in the major cotton producers of the world reducing the cost of production and with normal climatic conditions in China we expect a cotton price decline to the level predominating in the 21st century. With this moderate farm level price decline of 8 percent farmers shift from cotton more into the cereals with new technology and are able to maintain their incomes in this way.

The ultimate removal of the fertilizer subsidy pushed by the long term fiscal unsustainability is significantly detrimental to the household income. With the higher input costs, all the technology intensive activities decline including a 25 percent reduction of the new sorghum area. However, the declines are even greater for cotton and maize. Even with this fertilizer cost increase sorghum benefits from the improved marketing with sorghum being held for later sales while maize sales are increased at harvest for the harvest income requirement. The traditional sorghum activity expands substantially here; however, this expansion of traditional sorghum will not be sustainable without fertilization as it depletes the soil nutrients.

The bottom line here is that new sorghum technologies and marketing is facilitating the diversification away from cotton and will be expected to continue but at a slower rate even as the fertilizer subsidies are eliminated. Sorghum plays a very important role in smoothing the household income over time when the cotton price is reduced and the fertilizer subsidy is eliminated. So, there is a danger of not recognizing the potential of sorghum by only providing the fertilizer subsidy to cotton and maize as was the case before 2011.

Although we did not evaluate policies over an adjustment period, for food security reasons a short run (next 3 to 5 years) policy of keeping the fertilizer subsidies is recommended. There important learning by doing aspects of getting the moderate fertilizer employed and the rest of the agronomic practices right to accompany the improved cultivar. Moderate fertilizer needs to be side dressed not broadcast and a series of agronomic practices need to be adopted. So these changes need to be mastered by farmers to insure a high return to moderate fertilization (Coulibaly et al. 2011).

The welfare estimation of the various agricultural policies adopted at the household level shows that women are made better off from the increased household income. However, less labor intensive technologies such as the agricultural sorghum and marketing technologies provide a larger net income to women than policies to revamp the cotton sector. Policy initiatives that are less labor intensive allow for greater gains for women by enabling women to invest more labor time into the opportunity that maximizes their private income, i.e. their personal plot.

Overall, the findings from this research have several policy implications.

First, the improvement in the cotton industry caused by the substantial rise in cotton price and the allocation of fertilizer subsidy will be a short term effect given the predicted decline in the world cotton price and ultimately the reduction and elimination of the fertilizer subsidy. Cotton is expected to need more technological change to regain a leading position in this system. With 64 percent of world production in Bt cotton (James 2010) it is difficult to see how Mali can compete with countries that are able to substantially reduce costs with this cheaper and safer control of insect pests. So Mali will need to follow Burkina Faso[32] and rapidly incorporate this Bt gene into their improved cotton cultivars.

Simultaneously, we have shown the potential for cereal diversification in the cotton economy. This cereal technology is currently represented by the high yielding sorghum technologies accompanied by marketing strategies. It has been demonstrated in this dissertation and in the field (Coulibaly 2010, Coulibaly et al. forthcoming) that the cereal technology-marketing package can transform sorghum from a subsistence to a commercial crop. Bank credit is necessary and is increasingly made available in Mali.

Continued training of farmers' associations in marketing strategy and business management should enable them to further improve output prices and to prepare for the real price declining effect expected from the widespread introduction of later selling of sorghum. Higher sorghum prices are presently obtained through storage and late sales. In

[32] INERA (Institute for the Agricultural and Environmental Research) officials in Burkina Faso reported that 85 percent of the total cotton area in the 2010 crop year was grown with Bt cotton in Burkina Faso (John Sanders, informal interview 2011).

the future a demand expansion for sorghum stimulated by the development of the emerging animal feed processing industry for poultry industry is expected to be effective in moderating a price decline from widespread technology introduction. Also, large product sales and volume input purchases by farmers' associations will also benefit farmers.

Further, fertilizer subsidies are deemed fundamental for Mali to increase crop productivity, meet the food security challenges and contribute to fulfill the goal of transforming Mali into the regional cereals granary for the sub-Saharan region of Africa consistently with the Malian Agricultural Plans. Nonetheless, the large fiscal expenditures implied by the subsidy program are likely to constrain the long-term sustainability of this program. Strengthening the farmers' association ability to access and to modify fertilizer recommendations[33] over time is one way of getting the costs of fertilizer down. The farmers' associations can buy fertilizer in large quantities thereby reducing costs. Also as investments in infrastructure take place the cost of transport and other transaction costs related to long distance between the farm production entity and input and product markets will also be reduced. Continuing research and extension will also be useful to support the diversification activities and develop site specific fertilizer recommendations

Welfare evidence on women suggests that the most profitable economic opportunity for the household is not the most beneficial for women. Women are better off with the adoption of less labor intensive technologies on the communal plot. Therefore, initiatives to improve women's well-being must relax women's time on the communal plot to enable women to spend a higher amount of time on the private plot.

With the challenges facing women on access to land in terms of quantity and quality and also access to agricultural inputs, policy interventions for the private plot may need to target first access to better lands, compost and transportation to bring it to the

[33] The present moderate dose is one sack of DAP and one sack of Urea. Ultimately the lack of potassium will induce a deficiency in K and it will need to be applied. Sahelian soils tend to be deficient in P (phosphorous) and in organic matter. So N (nitrogen) and P were concentrated on in the initial fertilizer recommendations.

fields. Secondly, a continuing effort to increase access to agricultural inputs especially fertilizer and credit is necessary.

To increase women's income, other alternatives to the non-farm activities and to the private plot might be found in increasing the share of household income paid to women. Even though small, women receive a share of the household profit. With the new avenues for increasing household income and the bargaining type of decision making, there will be increasing pressure on the household head to raise the share of the income surplus from new technologies and marketing paid to women. Also, another strategy to increase women's welfare that was beyond the scope of analysis in this research is to reduce women's labor burden from the unpaid household chores. This could be made possible through access to household labor saving technologies in order to generate efficiency of women's time and release time opportunities for self-employment or income generating activities (Lawrence et al. 1999).

## 9.1 Directions for Future Research for the Farm Household

The discrete stochastic model used an average representative household to assess the income effect of agricultural technologies, marketing strategy and public policies. Using a representative average household does not take into account the impact of differences in assets, resource endowments, farming systems, and cash flow across households. There is a wide range of farmers with different resource endowments and such factors are expected to influence the extent of technology adoption and marketing patterns. A step further in this analysis would be to model those parameters and analyze how sensitive farmers' responses to some policy initiatives are to the household farming and economic conditions. This will help researchers, policy makers and development agencies to design technologies and policies that are best adapted to the household agronomic conditions and socio-economic characteristics and could be better focused on poverty alleviation.

The model was calibrated and the analysis performed with retail level grain prices. Farmers also sell in local and regional markets and sorghum is produced all over the country. Our retail price probably need to be slightly discounted for farm prices around harvest but the main difference then is transportation to specific agricultural areas with isolated or distant regions. The margins increase seasonally and we focused on this with the improved marketing option analyzed.

More information is always better than less but gathering good farm level data on a crop sold all over the country in small quantities over time will not be easy. Nevertheless, there should be some benchmark farm prices collected carefully for time of sale and location relative to regional markets. Analyzing these margins will also be interesting as improved transportation and communication over time is expected to continue to reduce them. Our primary marketing focus in this research was on reducing the large seasonal price spread between harvest and post-harvest price.

With increasing adoption of improved sorghum, there is potential for a structural market change in the long run. In the long run, with the increased production resulting from the adoption and the yield effect of the new sorghum will further reduce prices at harvest. The price difference after storage will then reflect storage cost and a return to entrepreneurs from taking the risk of holding the cereals. However, with the market expansion coming from the development of the poultry and the food processing industries, demand for sorghum will increase and moderate these real price declines. So, a step forward in the investigation after these future changes when the technology has been introduced on a widespread area will be to evaluate the price changes with the new market effects.

## 9.2. Direction for Future Research on Women

The welfare impact of technological change and agricultural policy on women was derived by using a partial budgeting approach with labor estimates from a farm household model. The share of income from the communal field was found by multiplying the household wealth derived from the model by a proportion of household income received by women based on household surveys. This proportion represented women's bargaining power from historic technological change. This bargaining power has been held constant across technologies and economic opportunities. In reality, we would expect women's bargaining power to increase with higher income generating opportunities. So, a model that will allow adjustment of bargaining power consistently with the economic opportunities would provide more insights. An empirical application of a Stackelberg oligopoly model (Warner and Campbell 2000) or Nash-cooperative bargaining model with asymmetry power (Svejnar 1986) between spouses may be appropriate for this purpose. Those models have been theoretically developed but there are still large avenues for empirical research in development.

Assessing the impact of agricultural technologies and government policy on women's welfare is a multifaceted area of investigation with ample dimensions. We focus on this research on the tangible measurable aspects of women's welfare. But there are untapped paths to evaluate welfare impact on women of policy initiatives and to design pragmatic policy actions to increase women's well-being. So, additional research that will require innovative approaches might take into consideration more of the benefits created by the increased household incomes that contribute to improve women's welfare. This could include improvements in housing, children education, household health, and improved diets resulting from new economic opportunity. This will require new intensive household surveys but would be a more complete response to the welfare impact on women from new technologies.

# LIST OF REFERENCES

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Abdoulaye, T. and J.H. Sanders. 2006. “New Technologies, Marketing Strategies and Public Policy for Traditional Food Crops: Millet in Niger.” *Agricultural Systems* 90: 292-292.

Adesina, A.A. and J.H. Sanders. 1991. “Peasant Farmer Behavior and Cereal Technologies: Stochastic Programming Analysis in Niger.” *Agricultural Systems* 5:21-38.

Adesina, A.A., P.C. Abbott, and J.H. Sanders. 1988. “Ex-ante Risk Programming Appraisal of New Agricultural Technology: Experiment Station Fertilizer Recommendations in Southern Niger.” *Agricultural Systems* 27(1):23-34.

Argawal, B. 1997. “Bargaining and Gender Relations: within and beyond the Household.” *Feminist Economics* 3(1): 1-51.

Ayele, S., and D. Wield. 2005. “Science and Technology Capacity Building and Partnership in African Agriculture: Perspectives on Mali and Egypt.” *Journal of International Development* 17:631-646.

Baquedano, F., J.H. Sanders, and J. Vitale. 2010. “Increasing Incomes of Cotton Farmers in Mali: Is Elimination of U.S. Subsidies the only Solution?” *Agricultural Systems* 103:418-432.

Bell, C. 1972. “The Acquisition of Agricultural Technology: its Determinants and Effects.” *Journal of Development Studies* 9:123-59.

Bourguignon, C. and P.A. Chiappori. 1992. “Collective Models of Household Behavior: an Introduction.” *European Economic Review* 36:355-364.

Carter, M.R. and K.D. Wiebe. 1990. “Access to Capital and its Impact of Agrarian Structure and Productivity in Kenya.” *American Journal of Agricultural Economics* 72:1146-50.

Cocks, K.D. 1968. “Discrete Stochastic Programming.” *Management Sciences* 15(1):72-79.

Commodities News 2011. Cotton Prices Forecast to Remain Strong in 2011-2012. http://www.commodities-now.com.

Coulibaly, O.N., J. Vitale, and J.H. Sanders. 1998. “Expected Effects of Devaluation on Cereal Production in the Sudanian Region of Mali.” *Agricultural Systems* 57(4):489-503.

Coulibaly Y. J. 2010. “Evaluation des Technologies de Production et de Commercialisation du Sorgho et du Mil dans le Cadre du Projet IER-INTSORMIL/MALI, USAID.” Bulletin IER-INTSORMIL n° 10.

Coulibaly Y. J., G. Kumaraswamy, and J.H. Sanders. 2011. “Economic Impact of Sorghum and Millet Technologies and Marketing in Mali.” Forthcoming IER-INTSORMIL/MALI Bulletin n° 11.

De Vuyst E.A., and P.V. Preckel. 2007. “Gaussian Cubature: A Practioner’s Guide.” *Mathematical and Computer Modeling* 45: 785-794.

Diakite L., E.K. Dembele, and M.A. Barry. 2009. Etude sur la Fourniture des Services Agricoles dans les Zones Cotonnières de l’Afrique de l’Ouest et du Centre (AOC). Rapport de Mission, Mali. Version Finale. ENDA Prospectives Dialogues Politiques.

Direction Nationale de la Météorologie, Mali. 2009. Relevé Pluviométrique Décadaire de 1980 à 2009.

Dolan, C. 2001. “The Good Wife: Struggle over Resources in the Kenyan Horticultural sector.” *Journal of Development Studies* 37(3): 39-70.

Dorward, A.R. 1996. “Modeling Diversity, Change and Uncertainty in Peasant Agriculture in Northern Malawi.” *Agricultural Systems* 51(4):469-486.

Dorward, A., E. Chirwa, V. Kelly, T. S. Jayne, R. Slater, and D. Boughton. 2008. Evaluation of the 2006/07 Agricultural Input Subsidy Programme, Malawi. Final Report. Lilongwe, Malawi.

Droy, I. 2008. “Le Coton Bio-équitable au Mali : un Facteur de Transformation Sociale. ” Working Paper. IRD-UMR C3 ED.

Fass, D. 2005. “Approximation of Discrete Multivariate Probability Distributions: Recursive and Hierarchical Approaches.” Unpublished Paper.

Fafchamps, M. 1993. “Sequential Labour Decisions under Uncertainty: an Estimable Household Model of West African Farmers.” *Econometrica* 615:1173-97.

Folbre, N. 1986. “Hearts and Spades. Paradigms of Household Economics.” *World Development* 14(2):145-255.

FAO, 2010. Current World Fertilizer Trends and Outlook to 2014. FAO, Rome.

Gladwin C.H., and D. Mc Millan. 1989. “Is a Turnaround in Africa Possible without helping African Women to Farm?” *Economic Development and Cultural Change* 37(2):345-370.

Harrigan, J. 2008. “Food Insecurity, Poverty and the Malawian Starter Pack: Fresh Start or False Start?” *Food Policy* 3: 237-249.

Hazell, P.B.R. and R.D. Norton. 1986. *Mathematical Programming for Economic Analysis in Agriculture*. Macmillan, New York.

Heath J.A. and D.H. Ciscel. 1988. “Patriarchy Structure and the Exploitation of Women’s Labor.” *Journal of Economic Issues* 22(3):781-794.

Hopkins, J., C. Levin, and L. Haddad. 1994. “Women’s Income and Household Expenditure Patterns: Gender and Flow? Evidence from Niger.” *American Journal of Agricultural Economics* 76 (5): 1219-1225.

ICAC. 2011. Lower World Cotton Prices in 2011/12. International Cotton Advisory Committee, August 1st 2011. Washington D.C.

IFA, 2011. Fertilizer Outlook 2011-2015. 79th IFA Conference Montreal (Canada) 23-25 May 2011. International Fertilizer Industry Association.

James, C. 2010. Global Status of Commercialized Biotech/GM Crops: 2010, ISAAA Brief No 42. ISAAA: Ithaca, NY.

Jones, C. 1983. The Impact of the SEMRY I Irrigated Rice Production and Consumption at the Intra-household Level. Paper presented for the United States Agency for International Development, 20 April 1983.

Kelly, V. and E. Crawford. 2010. Panacea or Pandora's Box: Fertilizer Subsidy Impacts and Recommendations for Improving Fertilizer Performance. Unpublished paper presented at USAID/Washington on October 4, 2010.

Kumar, S.K. 1987. Women's Role and Agricultural Technology. In: Mellor, J.W.., Delgado, C.L., Blackie, J.M. Eds. *Accelerating Food Production in Sub-Saharan Africa*, Chap. 10. John Hopkins University Press, Baltimore, MD.

Lado, C. 1992. "Female Labor Participation in Agricultural Production and the Implications for Nutrition and Health in Africa." *Social Sciences and Medicine* 34 (7): 789-807.

Lawrence, P.G., J.H. Sanders, and S. Ramaswamy. 1999. "The Impact of Agricultural and Household Technologies on Women: A Conceptual and Quantitative Analysis in Burkina Faso." *Agricultural Economics* 20(3): 203-214.

Lilja, N. and J.H., Sanders. 1998. "Welfare Impacts of Technological Change on Women and Children in Southern Mali." *Agricultural Economics* 19: 73-79.

Lopez-Pereira, M.A., J.H. Sanders, T.G., Baker and P.V., Preckel. 1994. "Economics of Erosion-Control and Seed-Fertilizer Technologies for Hillside Farming in Honduras." *Agricultural Economics* 11:271-288.

Maatman, A.C., C. Scweigman, A. Ruijs, M.H. and Van der Vlerk. 2002. "Modeling Farmers' Response to Uncertain Rainfall in Burkina Faso: A Stochastic Programming Approach." *Operations Research* 50(3): 399-414.

Malian Ministry of Agriculture. 2010. Statistics of Agricultural Production 1998-2008.

Manser, M. and M. Brown. 1980. "Marriage and Household Decision Making: a Bargaining Analysis." *International Economic Review* 21:31-44.

McElroy, M.B. and M.J. Horney. 1981. Nash Bargained Decisions: Towards a Generalization of the Theory of Demand. *International Economic Review* 22:333-349.

Minot, N., and T. Benson. 2009. "Fertilizer Subsidies in Africa." International Food Policy Research Institute, Issue Brief 60.

Nubukpo, K., and M.S. Keita. 2005. "L'impact sur l'Economie Malienne du Nouveau Mécanisme de Fixation du Prix du Coton Graine." Report of a Study Commissioned by Oxfam International. Oxfam, Dakar, Senegal.

Preckel, V. P. 2008. Quantitative Economic Analysis via Mathematical Programming. Department of Agricultural Economics. Purdue University.

Rae, A.N. 1971. "An Empirical Application and Evaluation of Discrete Stochastic Programming in Farm Management." *American Journal of Agricultural Economics* 53(4): 625-638.

Ricker-Gilbert J., T.S. Jayne, and E. Chirwa. 2011. "Subsidies and Crowding Out: A Double-Hurdle Model of Fertilizer Demand in Malawi." *American Journal of Agriculture* 93(1):26-42.

Sanders, J.H., B.I. Shapiro, and S. Ramaswamy. 1996. *The Economics of Agricultural Technology in Semi-arid sub-Saharan Africa*. John Hopkins University Press, Baltimore , M.D.

Savadogo, k., J.H. Sanders, and D.E.Mc Millan. 1989. Farm and Female Incomes and Productivities in the River Blindness Settlement Programs of Burkina Faso. Unpublished paper, Institute for Development Anthropology, Binghmton, N.Y.

Schultz, T.P. 1990. "Testing the Neoclassical Model of Family Labor Supply and Fertility." *Journal of Human Resources* 25(4): 599-634.

Sen, A.K. 1990. "Gender and Cooperative Conflicts." In I.Tinker, ed., *Persistent Inequalities*: Women and World development. New York: Oxford University Press.

Shapiro, B.I., J.H. Sanders, and K.C. Reddy. 1983. "Evaluating and Adapting New Technologies in a High-Risk Agricultural System, Niger." *Agricultural Systems* 42(1-2): 153-171.

Smale M., R.E. Just, and H.D. Leathers. 1994. "Land Allocation in HYV Adoption Models: An Investigation of Alternative Explanations." *American Journal of Agricultural Economics* 76(3):535-546.

Svejnar, J. 1986. "Bargaining Power, Fear of Disagreement and Wage Settlements: Theory and Evidence from U.S. Industry." *Econometrica* 54:1055-1078.

Thomas, D. 1997. Income, Expenditure, and Health Outcomes: Evidence on Intrahousehold Resource Allocation. In L. Haddad, J. Hoddinot and H. Alderman, *Intrahousehold Resources Allocation in Developing Countries*, pp 142-164. Baltimore and London: Johns Hopkins University Press.

Vitale, J.H. and J.H. Sanders. 2005. “New Markets and Technological Change for the Traditional Cereals in Semi-arid sub-Saharan Africa: the Malian Case.” *Agricultural Economics* 32:11-129.

Vitale, J.H., T.Boyer, R. Uaiene, and J.H. Sanders. 2007. “The Economic Impacts of Introducing Bt Technology in Smallholder Cotton Production Systems of West Africa: A Case Study from Mali.” *The Journal of Agrobiotechnology Management and Economics* 10(2): 71-84.

Warner, J.M. and D.A. Campbell. 2000. “Supply Response in an Agrarian Economy with Non-Symmetric Gender Relations.” *World Development* 28(7):1327-1340.

APPENDICES

# Appendix A: Yield Variability

Real aggregate yield observations and monthly prices were only available for a 10 years period going from 1998 to 2007. However, to be able to fit any appropriate distribution to the data, a larger number of observations are required. Given that traditional crop yields in the study area are mainly influenced by rainfall, observations on rainfall from 1980 to 2009 were used to simulate crop yields for the missing years of observations that means from 1980 to 1997 and from 2007 to 2009. In the study region, the likelihood of excess rainfall in the months of August and September makes flooding sometimes a constraint to adequate plant maturation and good crop yields. Thus, a quadratic term in rainfall was added in the regressions to characterize the decreasing crop yield with excess of rainfall. So, the grain yield regression equations are described as follows:

$$y_{it} = \beta_{0i} + \beta_{1i} X_t + \beta_{2i} X_t^{\ 2} + \varepsilon_{it}$$

Where $y_{it}$ is the yield of the grain *i* (millet, sorghum and maize) in year $t$ , $X_t$ and $X_t^2$ are respectively the rainfall observation and the quadratic term for rainfall in year *t*, $\varepsilon_{it}$ is the random term associated with the grain *i* in year *t*. $\beta_{0i}$ , $\beta_{1i}$ and $\beta_{2i}$ are the slope coefficients associated to the different variables. The results of the regressions are plotted in figures A.1 through A.3.

For cotton, in addition to rainfall, exogenous cotton prices set by the parastatal company at the beginning of the agricultural season are expected to impact the allocation of land to cotton and influence significantly cotton yield. Therefore, cotton prices from 1980 to 2009 were added in the cotton yield regression equation as shown below:

$$y_{ct} = \beta_{0c} + \beta_{1c} X_t + \beta_{2c} X_t^2 + \beta_{3c} P_{ct} + \varepsilon_{ct}$$

Where $y_{ct}$ is the cotton yield in year *t*, $P_{ct}$ is the cotton price in year *t*, $\varepsilon_{ct}$ is the random term for the cotton yield regression, $\beta_{0c}$ , $\beta_{1c}$ , $\beta_{2c}$ and $\beta_{3c}$ are the slope coefficients associated to the different variables. The result of the regression of cotton yield as a function of rainfall and price is reported in table A.1.

In total, instead of 10 years of observations, the expanded sample for crop yields contains 29 observations including both real yield data and simulated yields. One year of observation (1984) was dropped because of inconsistency in the data. The first order moment and second order moments represented by the mean and the covariance matrix for the original sample (10 observations) and the expanded one (29 observations) were calculated. The results reported in tables A.2 through A.4 show a good match between these two samples which means that the expanded sample is a good representation of the sample of real yield observations and can thereby be used to construct a suitable yield distribution.

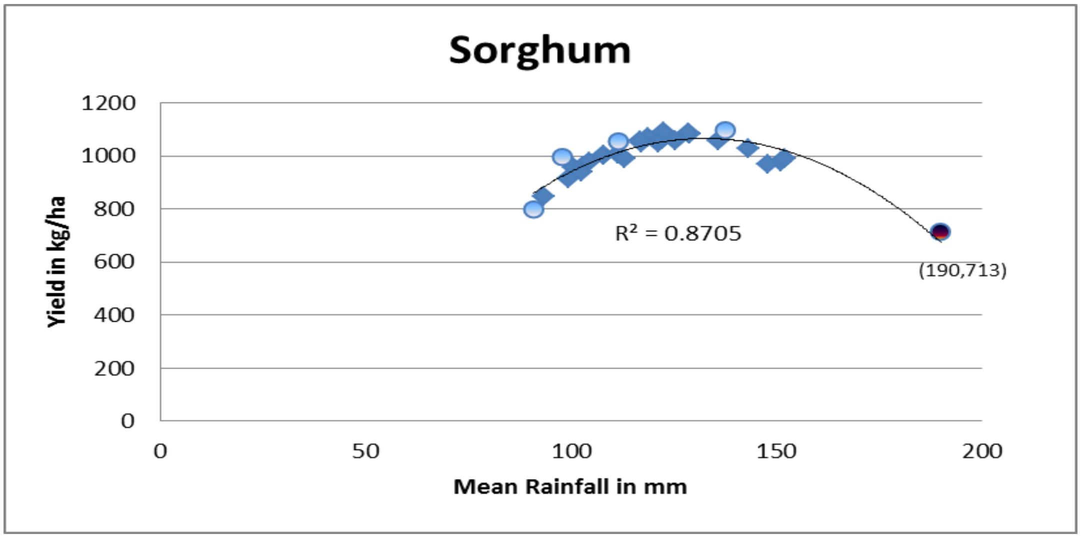


Figure A.1 Yield of Sorghum versus Mean Rainfall for the time series 1980 to 2009

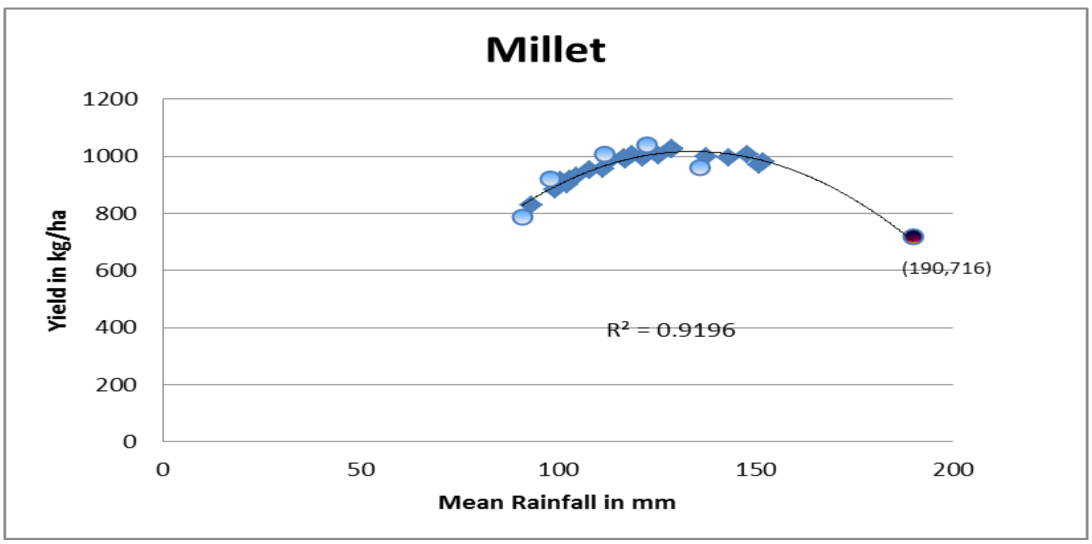


Figure A.2 Yield of Millet versus Mean Rainfall for the time series 1980 to 2009

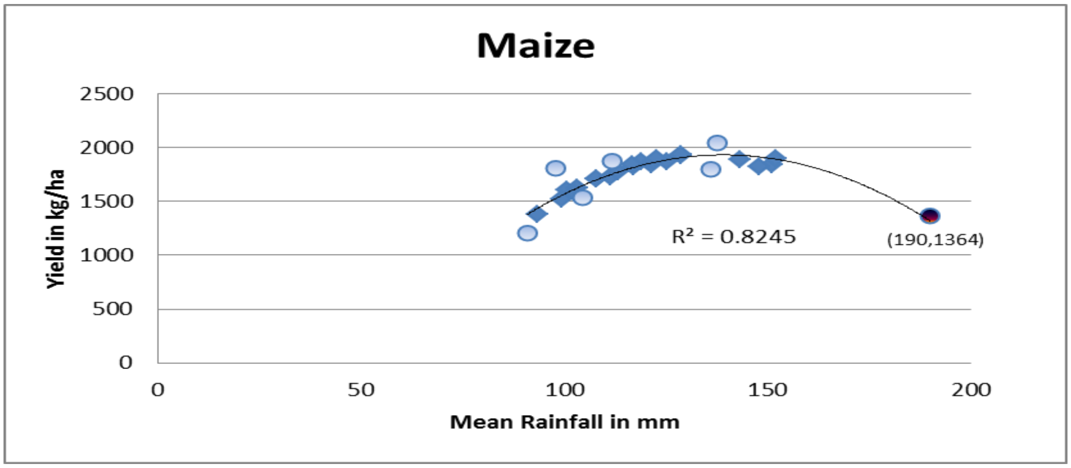


Figure A.3 Yield of Maize versus Mean Rainfall for the time series 1980 to 2009

In the graphs, circles are the yields of observed data from 1998 to 2007. Dark lozenges are the yields of the predicted data in 1994 that have been replaced by the discounted observed data for this year. For cotton, we were able to have real yield data for that year 1994. The squares are the predicted yields. Observations for the year 1984 have been dropped. Cotton yields are also function of cotton prices.

Table A.1. Cotton Yields versus Rainfall and Cotton Prices

| Yield | Intercept | Price Coefficient | Rainfall | Rainfall^2 | Adjusted $R^2$ | F | Standard deviation of the residuals |
|---|---|---|---|---|---|---|---|
| Cotton | --3050.75** (1166.40) | 3.15** (0.89) | 53.59** (18.47) | -0.21** (0.07) | 0.63 | 6.13** | 68.91 |

N=10 and standard error of the coefficients are reported in parentheses
***= significance at 1 % level of confidence, **= significance at 5 % level of confidence and *=significance at 10% level of confidence

Statistics for the Real Data Set (1998 to 2007)

Table A.2. Crop Average Yields for the Real data Set (1998 to 2007)

| | Millet Yield | Sorghum Yield | Maize Yield | Cotton Yield |
|---|---|---|---|---|
| Average Yield (kg/ha) | 961 | 1002 | 1765 | 966 |

Table A.3. Variance/Covariance Matrix for the Real Data Set

| | *Millet* | *Sorghum* | *Maize* | *Cotton* |
|---|---|---|---|---|
| Millet | 5,117.06 | | | |
| Sorghum | 5,309.67 | 7,339.57 | | |
| Maize | 14,970.20 | 17,883.7 | 54,611.7 | |
| Cotton | 3,357.93 | 6,615.84 | 11,774.7 | 19,309.4 |

Statistics for the Expanded Data Set (1980 to 2009) *

Table A.4 Crop Average Yields for the Expanded data Set (1980 to 2009)

| | Millet Yield | Sorghum Yield | Maize Yield | Cotton Yield |
|---|---|---|---|---|
| Average Yield (kg/ha) | 953 | 996 | 1745 | 968 |

*: Observation in 1984 has been dropped

Table A.5 Variance/ Covariance matrix for the Expanded data Set

| | *Millet* | *Sorghum* | *Maize* | *Cotton* |
|---|---|---|---|---|
| Millet | 5,453.92 | | | |
| Sorghum | 6,271.76 | 7,934.58 | | |
| Maize | 13,210.3 | 15,649.9 | 37,934.6 | |
| Cotton | 2,761.89 | 4,258.32 | 9,196.34 | 12,350.5 |

*: Observation in 1984 has been dropped

# Appendix B: Distribution of Yields and Prices

## Joint Multivariate Distribution of Yields using Gaussian Quadrature

A multivariate joint distribution was used to derive yield states of nature because of the high correlation between crop yields. The multivariate normal distribution is the most commonly employed multivariate parametric distribution for empirical work. Direct representation of joint multivariate is computationally cumbersome and might lead to the issue of the “curse of dimensionality”. As the number of variables grows, the size of the matrix required to obtain good estimates of the joint probability distribution grows exponentially (Fass 2005). Therefore, to avoid the difficulties inherent to direct estimation of joint multivariate distribution, a discrete approximation of the joint multivariate distribution is required.

The Gaussian Quadrature is the approach selected to generate discrete approximations of the joint multivariate distribution. The Gaussian quadrature method has two main advantages over some alternative approximation methods. First, the Gaussian quadrature is simple to implement and avoids the complexity of evaluating numerically the integral function. Second, the number of points necessary to get a good approximation are lesser and more accurate than those obtained with some other approaches such as the Direct Expected Utility Maximizing Program using Quadrature. Therefore, it reduces the likelihood of occurrence of the curse of dimensionality limiting often the implementation of Discrete Stochastic Program and other dynamic models.

The Gaussian Quadrature is a technique that uses moments to construct distributions. It is based on selecting points among random variables and their corresponding weights in such a way that the moments of the discrete approximation match the moments of the true distribution (De Vyust and Preckel 2007). The points can be interpreted as states of nature and the weights as the probabilities associated to the states of nature.

The Gaussian Quadrature approach to numerical integration approximates the integral of the product of two functions g(x) and f(x).

$$\int g(x,y)f(x)d(x)=\sum_{j=1}^{n}p^{j}g(x^{j},y)$$

Where $g(x,y)$ is the level of profit realized when state of nature *x* is realized and the decision *y* is selected. *y* is a vector of decision variables.

$x=[x_i]_{i=1,\dots,m}$ is a vector of *m* independent random variables. In the case of yield, we have four yields random variables for the traditional technologies and 5 yields random variables including the improved sorghum cultivar. $f(x)$ is the joint probability density function for the random variables. $p^j$ is the weight or the probability associated with the vector of points $x^j$. The sum of the probabilities must be equal to 1.

With the Gaussian Quadrature, the probabilities of realization of a set of vectors of random variables are found by solving a programming problem. There is no objective in this programming problem but the constraints specify that the mean and the second order moment about zero must match the same moments of the original distribution. In addition, the sum of the probabilities of occurrence of the set of vectors must be equal to 1. The application of the Gaussian Quadrature approach to approximate the original distribution of yield random variables leads to 17 points or set of random variables vectors with positive probability (see table B.1).

Table B.1 States of nature of Yields (kg/ha) and their Corresponding Probabilities

| Points | Cotton | Maize | Sorghum | Millet | New Sorghum | Probability |
|---|---|---|---|---|---|---|
| 1 | 939 | 1715 | 1005 | 951 | 1642 | 0.171 |
| 2 | 781 | 1383 | 846 | 830 | 1483 | 0.069 |
| 3 | 909 | 1841 | 976 | 968 | 1613 | 0.128 |
| 4 | 962 | 1621 | 962 | 918 | 1599 | 0.025 |
| 5 | 1028 | 1364 | 713 | 716 | 1350 | 0.026 |
| 6 | 1143 | 1727 | 1005 | 954 | 1642 | 0.089 |
| 7 | 1031 | 1823 | 971 | 1007 | 1608 | 0.023 |
| 8 | 953 | 1903 | 1090 | 1039 | 1727 | 0.14 |
| 9 | 1009 | 1538 | 978 | 931 | 1615 | 0.015 |
| 10 | 1111 | 1868 | 1056 | 1006 | 1693 | 0.072 |
| 11 | 777 | 1207 | 798 | 785 | 1435 | 0.034 |
| 12 | 1145 | 1800 | 1059 | 958 | 1696 | 0.047 |
| 13 | 1063 | 1804 | 994 | 921 | 1631 | 0.037 |
| 14 | 767 | 1896 | 991 | 979 | 1628 | 0.007 |
| 15 | 1005 | 2040 | 1095 | 1000 | 1732 | 0.049 |
| 16 | 824 | 1578 | 939 | 901 | 1500 | 0.034 |
| 17 | 875 | 1941 | 1088 | 1026 | 1800 | 0.034 |

Distribution of Prices

In regards to the distribution of prices at the different decision periods, the residuals of the prices regression equations were used to construct distributions and to derive the probabilities associated to the states of nature. A Gaussian Quadrature approximation can be used also in this case to identify the probabilities of the price states of nature but given the 10 price observations an empirical distribution will produce exactly the same results as the Gaussian Quadrature approximation. Thus, the empirical distribution identifies each year of the 10 years period as a single state of nature, with the probability 1/10 attached to each outcome. Thus, 10 states of nature with a probability of 1/10 for each event have been identified for prices at harvest, in the recovery and the lean seasons (see tables B.2, B.3 and B.4).

Table B.2 Probability Distribution of the Residuals for the Grain Harvest Prices regressed on Yields

| States | Maize | Millet | Sorghum | Probability |
|---|---|---|---|---|
| 1 | 17.15 | 52.062 | 18.629 | 0.1 |
| 2 | -10.49 | -0.439 | 8.598 | 0.1 |
| 3 | -27.381 | -34.372 | -33.667 | 0.1 |
| 4 | 21.602 | 26.859 | 34.321 | 0.1 |
| 5 | 17.58 | 23.978 | 14.514 | 0.1 |
| 6 | -31.104 | -27.889 | -22.948 | 0.1 |
| 7 | 4.114 | -9.403 | -4.772 | 0.1 |
| 8 | 5.425 | 9.188 | 0.011 | 0.1 |
| 9 | -12.872 | -24.624 | -26.502 | 0.1 |
| 10 | 15.975 | -15.359 | 11.816 | 0.1 |

Table B.3 Probability Distribution of the Residuals of Grain Recovery Prices regressed on Harvest Prices

| States | Maize | Millet | Sorghum | Probability |
|---|---|---|---|---|
| 1 | -6.869 | -31.622 | -6.994 | 0.1 |
| 2 | -23.026 | -41.915 | -30.45 | 0.1 |
| 3 | 23.895 | 39.602 | 28.375 | 0.1 |
| 4 | 35.079 | 44.288 | 47.948 | 0.1 |
| 5 | -24.764 | -2.52 | -22.55 | 0.1 |
| 6 | -11.631 | -27.275 | -14.73 | 0.1 |
| 7 | 41.447 | 39.939 | 44.667 | 0.1 |
| 8 | -14.632 | -3.319 | -11.263 | 0.1 |
| 9 | -13.973 | -15.398 | -19.578 | 0.1 |
| 10 | -5.526 | -1.78 | -15.426 | 0.1 |

Table B.4 Probability Distribution of the Residuals of prices in the Hungry Season regressed on prices in the Harvest and Price Recovery Periods

| States | Maize | Millet | Sorghum | Probability |
|---|---|---|---|---|
| 1 | -0.831 | 7.423 | -0.651 | 0.1 |
| 2 | -6.547 | 1.539 | -7.764 | 0.1 |
| 3 | -10.977 | -11.945 | -2.708 | 0.1 |
| 4 | 11.474 | -3.798 | -3.889 | 0.1 |
| 5 | -9.898 | -8.277 | -1.952 | 0.1 |
| 6 | -6.321 | -4.041 | -14.567 | 0.1 |
| 7 | -11.152 | 17.561 | 5.125 | 0.1 |
| 8 | -10.885 | -5.631 | -5.557 | 0.1 |
| 9 | 7.445 | -7.498 | 8.349 | 0.1 |
| 10 | 37.693 | 14.668 | 23.614 | 0.1 |

# Appendix C: Yield, Rainfall and Price Data

Table C.1: Yield, Rainfall and Cotton Price Data from 1980 to 2009

| Years | Millet | Traditional Sorghum | Improved Sorghum | Maize | Cotton | Rainfall | Nominal Cotton Price | Real Cotton Price |
|---|---|---|---|---|---|---|---|---|
| 1980 | 951 | 1005 | 1642 | 1715 | 939 | 108 | 55.00 | 212 |
| 1981 | 994 | 1051 | 1688 | 1846 | 1043 | 121 | 65.00 | 230 |
| 1982 | 1005 | 1070 | 1707 | 1870 | 1058 | 119 | 65.00 | 227 |
| 1983 | 951 | 1005 | 1642 | 1715 | 958 | 108 | 75.00 | 218 |
| 1985 | 988 | 1048 | 1685 | 1824 | 970 | 117 | 85.00 | 207 |
| 1986 | 1001 | 1056 | 1693 | 1871 | 987 | 125 | 85.00 | 211 |
| 1987 | 913 | 958 | 1595 | 1606 | 893 | 101 | 85.00 | 214 |
| 1988 | 1022 | 1082 | 1719 | 1931 | 1028 | 129 | 85.00 | 215 |
| 1989 | 830 | 846 | 1483 | 1383 | 778 | 93 | 85.00 | 219 |
| 1990 | 968 | 976 | 1613 | 1841 | 906 | 151 | 93.00 | 221 |
| 1991 | 1001 | 1061 | 1698 | 1866 | 1070 | 122 | 95.00 | 235 |
| 1992 | 882 | 914 | 1551 | 1523 | 826 | 99 | 85.00 | 209 |
| 1993 | 918 | 962 | 1599 | 1621 | 957 | 103 | 97.50 | 233 |
| 1994 | **716** | **713** | 1350 | **1364** | *1028* | 190 | 130.00 | 219 |
| 1995 | 996 | 1059 | 1696 | 1843 | 1046 | 117 | 155.00 | 227 |
| 1996 | 954 | 1005 | 1642 | 1727 | 1145 | 111 | 185.00 | 278 |
| 1997 | 995 | 1026 | 1663 | 1893 | 1053 | 143 | 170.00 | 247 |
| 1998 | *1007* | *971* | 1608 | *1823* | *1031* | 148 | 185.00 | 262 |
| 1999 | *1039* | *1090* | 1727 | *1903* | *953* | 123 | 150.00 | 214 |
| 2000 | *931* | *978* | 1615 | *1538* | *1009* | 105 | 170.00 | 224 |
| 2001 | *1006* | *1056* | 1693 | *1868* | *1111* | 112 | 200.00 | 252 |
| 2002 | *785* | *798* | 1435 | *1207* | *777* | 91 | 180.00 | 235 |
| 2003 | *958* | *1059* | 1696 | *1800* | *1145* | 136 | 200.00 | 255 |
| 2004 | *921* | *994* | 1631 | *1804* | *1063* | 98 | 210.00 | 255 |
| 2005 | *983* | *989* | 1626 | *1773* | *798* | 113 | 160.00 | 188 |
| 2006 | *979.4* | *991* | 1628 | *1896* | *767* | 152 | 165.00 | 184 |
| 2007 | *1000* | *1095* | 1732 | *2040* | *1005* | 138 | 160.00 | 174 |
| 2008 | 901 | 939 | 1500 | 1578 | 825 | 102 | 200 | 200 |
| 2009 | 1026 | 1088 | 1800 | 1941 | 875 | 129 | 170.00 | 164 |
| Mean | **953** | **996** | **1633** | **1745** | **967** | **121** | **133** | **222** |

Note: data in bold are real data from the region of Sikasso in 1994 discounted by a percentage to reflect the yields in Koutiala. The discount rates are bias observed between yields of Koutiala and Sikasso from 1998 to 2007. Over this time period, yields of millet in Sikasso are on average 7 percent higher than millet yields in Koutiala. Sorghum and maize yields are respectively 5 percent and 1 percent lower in Sikasso than yields in Koutiala. Those discount rates were applied to find the estimated yields in 1994 in Koutiala for millet, sorghum and maize.
Data in italic are the observed yields in Koutiala from 1998 to 2007
Data in regular font are the predicted yields obtained with the regression equations
For the improved sorghum, we had only three years of field observations (2007 to 2009), so we computed first the difference in the average yield between the traditional cultivar and the improved one during those years. Then we found the yields of the improved sorghum for the 26

years with missing observations by adding this average value to the yields of the traditional sorghum variety.
Rainfall data are average monthly observations in mm.
Cotton real prices have been obtained by deflating the nominal prices using the GDP (Gross Domestic Product) deflator index in Mali with 2008 as the base year. The resulting predicted cotton yields appear to be more consistent with the observed trend in yields when the GDP deflator is used to correct for inflation than the CPI (Consumer Price Index).

Table C.2: Sorghum Real Prices from 1998 to 2008

| Years | Harvest Season Prices | Recovery Season Prices | Hungry Season Prices |
|---|---|---|---|
| 1998 | 119 | 135 | 124 |
| 1999 | 80 | 73 | 65 |
| 2000 | 65 | 117 | 153 |
| 2001 | 114 | 185 | 202 |
| 2002 | 157 | 157 | 115 |
| 2003 | 56 | 65 | 72 |
| 2004 | 90 | 158 | 196 |
| 2005 | 96 | 108 | 103 |
| 2006 | 69 | 73 | 93 |
| 2007 | 82 | 90 | 120 |
| 2008 | 80 | 109 | 138 |
| Mean | 92 | 115 | 126 |

Note: Prices have been deflated with GDP deflator by using 2008 as the base year.

# Appendix D: GAMS Model

```
*%%%%% Jeanne DSP model%%%%%%%
*1. Finding the probabilities of the different states of nature

Option
limrow=0
limcol=0 ;

Sets

inp input for crops /npkc, ureac, herb, insect,seedc,npkm,uream, seedma, seedmi,seedsor, urea2,
dap,seedntso/

lper labor period /L1*L10 /

crop all crops in the model /cot,maiz,mil,sorg/

grain(crop) grain consumed in the household hold / mil, sorg, maiz/

cropact all crop activities used in the model / trdct, trdma, trds, trdmi,ntso/
*trdct=traditonal cotton, trdma=traditonal maize, trds=traditional sorghum, trdmi= traditional
millet, Ntso=new technology for sorghum
trad(cropact) traditional activities /trdct, trdma, trds, trdmi/
gtrad(trad) traditional activities except cotton / trdma, trds, trdmi/

t time period /t1*t29/
*time from 1980  to 2009 with 1984 dropped
ty(t) subset time period when we have real yield data /t18*t27/
*time from 1998 to 2007
sy(t) subset time period when yield probabilities is not equal to
zero/t1,t9,t10,t13,t14,t16,t18,t19,t20,t21,t22,t23,t24,t26,t27,t28,t29/
labor family labor /male, female, child/
alias (cropact,j),(trad,trd),(grain,gr) ;
alias (ty,ty1,ty2,ty3);




Table outmap(cropact,crop) Which crop activities produce which crops
        cot  maiz  mil   sorg
trdct    1
trdma          1
trds                        1
trdmi                1
ntso                          1 ;
```

```
Parameter

table yield(t,*) predicted and real yield data in kg per ha
         trdmi     trds     trdma     trdct     ntso
t1        951      1005     1715       939      1642
t2        994      1051     1846      1042      1688
t3       1005      1070     1870      1058      1707
t4        951      1005     1715       963      1642
t5        988      1048     1824       969      1685
t6       1001      1056     1871       990      1693
t7        913       958     1606       895      1595
t8       1022      1082     1931      1026      1719
t9        830       846     1383       781      1483
t10       968       976     1841       909      1613
t11      1001      1061     1866      1068      1698
t12       882       914     1523       828      1551
t13       918       962     1621       962      1599
t14       716       713     1364      1028      1350
t15       996      1059     1843      1046      1696
t16       954      1005     1727      1143      1642
t17       995      1026     1893      1053      1663
t18      1007       971     1823      1031      1608
t19      1039      1090     1903       953      1727
t20       931       978     1538      1009      1615
t21      1006      1056     1868      1111      1693
t22       785       798     1207       777      1435
t23       958      1059     1800      1145      1696
t24       921       994     1804      1063      1631
t25       983       989     1773       798      1626
t26       979       991     1896       767      1628
t27      1000      1095     2040      1005      1732
t28       901       939     1578       824      1500
t29      1026      1088     1941       875      1800 ;

Positive Variables
pry(t)      Probability on the t-th yield ;
Variables
z           Dummy objective ;
Equation
obj         Dummy objective definition
prysum      Probabilities add to 1
mu(cropact)      Means of crop yields
sig(cropact,cropact) Covariances of crop yields ;
obj .. z =e= 0 ;
prysum .. sum(t,pry(t)) =e= 1 ;
mu(cropact) .. sum(t,pry(t)*yield(t,cropact)) =e= sum(t,yield(t,cropact))/card(t) ;
sig(cropact,j) .. sum(t,pry(t)*yield(t,cropact)*yield(t,j))
 =e= sum(t,yield(t,cropact)*yield(t,j))/card(t) ;
Model GQYields / obj,prysum,mu,sig / ;
```

```
Option limrow=1,limcol=1 ;
Solve GQYields using lp minimizing z ;
scalar nstate Number of states ;
nstate = sum(t$pry.l(t),1) ;
display nstate ;
yield(t,'prob') = pry.l(t) ;
display yield ;


Table map(cropact,crop)  Mapping from crops to grains
         mil   sorg  maiz cot
trdmi    1
trds            1
trdma               1
trdct                         1
*ntso           1            ;

Parameter
rainfall(t) average monthly rainfall across time periods
/t1 108, t2 121, t3 119, t4 108, t5 117, t6 125, t7 101, t8 129, t9 93, t10 151,

t11 122, t12 99, t13 103, t14 190, t15 117, t16 111, t17 143, t18 148, t19 123,

t20 105, t21 112, t22 91, t23 136, t24 98, t25 113, t26 152, t27 138, t28 102, t29 129/

pcot(t) real cotton prices across time periods in F CFA per kg
/t1 212, t2 230, t3 227, t4 218, t5 207, t6 211, t7 214, t8 215, t9 219, t10 221,

t11 235, t12 209, t13 233, t14 219, t15 227 , t16 278, t17 247, t18 262, t19 214,

t20 224, t21 252, t22 235, t23 255, t24 255, t25 188, t26 184, t27 174, t28 200, t29 164/;
```

```
Table hvprice(t,grain)  Harvest time price for grain
         mil    sorg      maiz
t18     153     119       96
t19      94      80       64
t20      82      65       67
t21     128     114       98
t22     170     157      130
t23      83      56       49
t24     109      90       84
t25     115      96       87
t26      82      69       62
t27      87      82       83
t28     104      80       86
;
Table rcprice(t,grain)  Recovery time price for grain
        mil     sorg     maiz
t18     131      135      113
t19      69       73       64
t20     140      117      114
t21     185      185      157
t22     175      157      130
t23      74       65       60
t24     164      158      149
t25     126      108       96
t26      85       73       71
t27     103       90      101
t28     123      109      113
;
Table hnprice(t,grain)  Hungry time price for grain
        mil    sorg    maiz
t18     119      124      100
t19     70        65       63
t20     167      153      120
t21     204      202      167
t22     153      115       79
t23      80       72       73
t24     210      196      148
t25     128      103       77
t26      93        93      88
t27     137      120      136
t28     156      138      120
;

Variables
 calpha        Intercept for cotton yield
 cbetar        Rainfall slope for cotton yield
 cbetarr       Rainfall^2 slope for cotton yield
 cbetap        Price slope for cotton yield
 alpha(grain)   Intercept for harvest price of grain
```

```
 beta(grain)     Yield slope for price of grain
 rpalpha(grain) Intercept for regression of recovery price
 rpbeta(grain)  Slope for regression of recovery price
 hpalpha(grain) Intercept for regression of hungry price
 hphbeta(grain)  Slope for regression of hungry price for harvest price
 hprbeta(grain)  Slope for regression of hungry price for recovery price
 ssq           Regression sum of squares ;

Equation
lsqobj        Least squares objective ;
lsqobj .. sum(grain,sum(ty,sqr(hvprice(ty,grain)
  -alpha(grain)-beta(grain)*sum(cropact,map(cropact,grain)*yield(ty,cropact)))))
  + sum(ty,sqr(yield(ty,'trdct')-calpha-cbetar*rainfall(ty)
  -cbetarr*sqr(rainfall(ty))-cbetap*pcot(ty)))
  + sum(grain,sum(ty,sqr(rcprice(ty,grain)-rpalpha(grain)
  -rpbeta(grain)*hvprice(ty,grain))))
  + sum(grain,sum(ty,sqr(hnprice(ty,grain)-hpalpha(grain)
  -hphbeta(grain)*hvprice(ty,grain)
  -hprbeta(grain)*rcprice(ty,grain))))
=e= ssq ;
Model HPReg / lsqobj / ;
Solve HPReg using nlp minimizing ssq ;
Parameters
 rhvp(ty,*)  Residuals for grain harvest prices regressed on yield
 rrcp(ty,*)  Residuals for grain recovery prices regressed on harvest price
 rhnp(ty,*)  Residuals for grain hungry prices regressed on harvest and recovery prices ;
rhvp(ty,grain) = hvprice(ty,grain)
  -alpha.l(grain)-beta.l(grain)*sum(cropact,map(cropact,grain)*yield(ty,cropact)) ;
rrcp(ty,grain) =  rcprice(ty,grain)-rpalpha.l(grain)
  -rpbeta.l(grain)*hvprice(ty,grain) ;
rhnp(ty,grain) = hnprice(ty,grain)-hpalpha.l(grain)
  -hphbeta.l(grain)*hvprice(ty,grain)
  -hprbeta.l(grain)*rcprice(ty,grain) ;
rhvp(ty,'prb') = 1/card(ty) ;
rrcp(ty,'prb') = 1/card(ty) ;
rhnp(ty,'prb') = 1/card(ty) ;
yield(t,cropact)$(not yield(t,'prob')) = 0 ;

display yield,rhvp,rrcp,rhnp ;

**Deterministic prices and residuals
Parameter
hprice(t,ty,*);
hprice(t,ty,grain)=
alpha.l(grain)+beta.l(grain)*sum(cropact,map(cropact,grain)*yield(ty,cropact))+ rhvp(ty,grain);
hprice(t,ty,'prob')= pry.l(t)*1/card(ty);
hprice(t,ty,grain)$(not hprice(t,ty,'prob'))=0;
Parameter
rprice(t,ty1,ty2,*);
```

```
rprice(t,ty1,ty2,grain)= rpalpha.l(grain)+rpbeta.l(grain)*hprice(t,ty1,grain)+ rrcp(ty2,grain);
rprice(t,ty1,ty2,'prob')= pry.l(t)*1/card(ty)**2 ;
rprice(t,ty1,ty2,grain)$(not rprice(t,ty1,ty2,'prob'))=0;
Parameter
huprice(t,ty1,ty2,ty3,*);
huprice(t,ty1,ty2,ty3,grain)=
hpalpha.l(grain)+hphbeta.l(grain)*hprice(t,ty1,grain)+hprbeta.l(grain)*rprice(t,ty1,ty2,grain)+rhn
p(ty1,grain);
huprice(t,ty1,ty2,ty3,'prob')= pry.l(t)*1/card(ty)**3  ;
huprice(t,ty1,ty2,ty3,grain)$(not huprice(t,ty1,ty2,ty3,'prob'))=0;
display hprice,rprice,huprice;

Parameters

Table inpuse (cropact,inp) quantity of inputs used per activity
*seed= kg/ha; npk=kg/ha;  urea=kg/ha; herb=lt/ha;  insect=lt/ha  manure=kg/ha

          seedc   seedma  seedsor  seedntso seedmi   npkc   ureac   urea2   herb  insect dap  npkm
uream
trdct      30      0     0        0      0      150     50      0      3      5     0      0      0
trdma       0     20     0        0      0        0      0      0      2      0     0    100    100
trds        0      0     9        0      0        0      0      0      0      0     0      0      0
trdmi       0      0     0        0      5        0      0      0      0      0     0      0      0
ntso        0      0     0       10      0        0      0     50      0      0    50      0      0  ;



Table labusec (cropact,lper) qty of labor used on crop activity

*unit of labuse: pde=person day equivalent, 1pde=8 hours of work by an adult
* Human labor period definition see Coulibaly (1995)
*for the definition of the labor period, see Appendix IV in Coulibaly (1995)
*the definition of the labor periods vary per crop
*cot: L1=manure spray, L2= ridging, L3= seeding1 , L4=insecticide spray, L5= weeding and
fertil appl,
*L6= herbicide spray,  L7= weed2 (is zero because no 2nd manual weeding but with animal
traction), L7= mounting, L8= harvest L9= harvest
*maize: L1=manure spray, L2=ridging and seeding1, L4=fert&weeding1, L5=weeding2,
L6=mounting, L7=harvest, L8=harvest
*sorg and mil : L1=manure spray, L2=ridging, L3=seeding1, L4=seeding2&thining,
L5=weeding, L6=weeding, L7=weeding, L8=mounting, L9=harvest, L10=harvest
```

| | L1 | L2 | L3 | L4 | L5 | L6 | L7 | L8 | L9 | L10 |
|---|---|---|---|---|---|---|---|---|---|---|
| trdct | 24 | 51 | 6 | 8 | 72 | 5 | 0 | 26 | 280 | 149 |
| trdma | 30 | 51 | 0 | 58 | 50 | 51 | 20 | 210 | 0 | 0 |
| trds | 0 | 36 | 10 | 14 | 17 | 4 | 10 | 58 | 20 | 105 |
| trdmi | 0 | 36 | 10 | 14 | 17 | 4 | 10 | 58 | 20 | 105 |
| ntso | 24 | 36 | 10 | 14 | 17 | 4 | 10 | 58 | 20 | 105; |

Table labavail (labor,lper) family labor availability
*Adult members are composed of adult males, females and child labor
*labor are expressed in person day equivalent, 1 pde=8 hours
*Male adult works an average of 8 hours per day
*Female adult works an average of 6 hours a day, women are only available for planting, thinning and harvesting
*Child works an average of 4 hours per day

| | L1 | L2 | L3 | L4 | L5 | L6 | L7 | L8 | L9 | L10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Male | 208 | 104 | 104 | 96 | 96 | 72 | 120 | 208 | 208 | 208 |
| Female | 156 | 78 | 78 | 72 | 72 | 54 | 90 | 156 | 156 | 156 |
| Child | 104 | 52 | 54 | 48 | 48 | 32 | 60 | 104 | 104 | 104 ; |

Parameter

hirew(lper) wage (F CFA per day) hired labor
/L1 500, L2 500, L3 500, L4 500, L5 500, L6 500, L7 500, L8 500, L9 500, L10 500/

*incost(inp) /npk 268, urea1 268, herb 2888, insect 4510, seedc 34.5, seedma 400, seedmi 400, seedsor 400,urea2 300, dap 340,seedntso 120/
*Inputs Prices 2008
*incost(inp) /npkc 369, ureac 380, npkm 351,uream 380, herb 4500, insect 4510, seedc 34.5, seedma 400, seedmi 400, seedsor 400,urea2 350, dap 720,seedntso 120/
*Subsidized fert for sorgh=518, noS=615
*scenario P=231, all else constant
*incost(inp) /npkc 334, ureac 344, npkm 318,uream 344, herb 4078, insect 4088, seedc 31, seedma 363, seedmi 363, seedsor 363, urea2 317, dap 653,seedntso 109/
*scenario P=231,and fertilizer cost changed
incost(inp) /npkc 243, ureac 243, npkm 243,uream 243, herb 4078, insect 4088, seedc 31, seedma 363, seedmi 363, seedsor 363, urea2 243, dap 486,seedntso 109/

*scenario removal of fertilizer subsidy fertilizer cost at the 2011 market prices
*incost(inp) /npkc 342, ureac 303, npkm 335, uream 303, herb 4078, insect 4088, seedc 31, seedma 363, seedmi 363, seedsor 363, urea2 303, dap 671,seedntso 109/

*Inputs Prices 2008 and subsidized fertilizer price for all crops
*incost(inp) /npkc 243, ureac 243, npkm 243,uream 243, herb 4500, insect 4510, seedc 34.5, seedma 400, seedmi 400, seedsor 400,urea2 243, dap 486,seedntso 120/

```
Qstock1(crop) initial stock of grain at the begining of the planting season
/ cot 0, mil 1200, sorg 1500, maiz 1000/
farmlab(labor) number of active family member /male 4, female 3, child 3/
exrcprice(crop)/ cot 222, mil 125, sorg 115, maiz 106/

mincons1 minimum household requirement in stage 1 /5103/
mincons2 minimum household requirement in stage 2 /3645/
mincons3 minimum household requirement in stage 3 /2916/ ;

Parameter  Joint(t,ty,ty,ty) ;
Joint(t,ty1,ty2,ty3)=pry.l(t)* 1/card(ty1)*1/card(ty2)*1/card(ty3);

Scalar
*Scalar for the first stage
Icap1  initial capital /365000/
hhexp1 Household expenditures in the first stage /136240/
hhexp2 Household expenditures in the second stage /110000/
hhexp3 Household expenditures in the third stage /136240/
Harvreq harvest income requirement /163000/
pricecot announced cotton price /231/

Land1 constraint /12/
*Land constraint for millet
Land2 constraint /3/
socred /150000/
intrest/0.30/
land /15/

taum/0.20/
taus/0.32/
taumi/0.23/;

Positive Variables
cons1(crop)          Quantity of grain consumed during the agricultural season (kg)
Qsale1(crop)         Quantity of grain sold at the beginning of the planting season (kg)
Qpurch1(crop)        Quantity of grain purchased at the beginning of the planting season (kg)
Qtrans1(crop)        Quantity of grain transferred from planting to the end of harvest (kg)
Cashtrans1           Amount of cash transferred from the first period to the second one (F CFA)
Xha(cropact)         Area of land allocated to the different crops (ha)
totinp(inp)          Total quantity of purchased inputs used for the traditional technologies (kg)
Hlab(lper)           Agricultural labor hired on farm (man hours)
agprod(t,crop)       Harvest crop production (kg)
cons2 (crop,t,ty)     Quantity of grain consumed during the second period by yield and harvest
price state of nature (kg)
Qsale2(crop,t,ty)     Quantity of crop sold at harvest by yield and harvest price state of nature (kg)
Qpurch2 (crop,t,ty)    Quantity of grain purchased at harvest by yield and price state of nature
(kg)
Qtrans2(crop,t,ty)    Quantity of grain transferred from harvest to the recovering period by yield
and harvest price state of nature
```

Cashtrans2(t,ty) Amount of cash transferred from harvest to the recovering period by yield and harvest price state of nature
Cons3(grain,t,ty,ty) Quantity of grain consumed during the third period (kg)
Qsale3 (grain,t,ty,ty) Quantity of grain sold at the end of the recovering period by yield harvest price and recovering price state of nature (kg)
Qtrans3(grain,t,ty,ty) Quantity of grain transferred from the recovering period to the hungry season by yield harvest price and recovering price state of nature (kg)
Cashtrans3(t,ty,ty) Amount of cash transferred from the recovering period to the hungry season by yield harvest price and recovering price state of nature (kg)

```
Variable
Eprofit            Expected profit

;
Equations

GRAINBAL1                    Grain balance for the first period
GRAINCONS1                   Grain consumption first period
CASHBAL1                     Cash balance for the first period
LANDCROP1                    Land constraint for cotton, sorghum and maize
LANDCROP2                    Land constraint for millet
INUSE(inp)                   Input used constraint
FARMLABAV(lper)              Farm labor availability
GRAINBAL2                    Grain balance for the second period
APROD(crop,t)                Agricultural production
GRAINCONS2(t,ty)             Grain consumption second period
CASHBAL2(t,ty)               Cash balance second period
GRAINBAL3(grain,t,ty,ty)     Grain balance third period
GRAINCONS3(t,ty,ty)          Grain consumption third period
CASHBAL3(t,ty,ty)            Cash balance third period
OBJECTIVE                    Linear objective
HARVINC(t,ty)                Harvest income constraint
GRAINCONSS(crop,t,ty)        Grain consumption constraint related to agricultural production
COTONCRED(t)                 Cotton credit
NTSOCRED(t,ty,ty)            Improved sorghum credit
GRINK                        Improved sorghum credit constraint
LIMPURCH2(crop,t,ty)         Limit on grain purchase second period

;
GRAINBAL1 (crop)$(ord(crop) gt 1).. cons1(crop)+ Qsale1(crop)+ Qtrans1(crop)=l=
Qstock1(crop)+ Qpurch1(crop);
GRAINCONS1..sum((crop)$(ord(crop)gt 1), cons1(crop))=G= mincons1 ;

variable icap ;
positive variable borrow(t,ty);
CASHBAL1.. hhexp1 + sum((cropact)$((ord(cropact)gt 2)and(ord(cropact)lt
5)),sum((inp)$((ord(inp)gt 7)and (ord(inp)lt 11)), Xha(cropact)*inpuse(cropact,inp)*incost(inp)))
 + exrcprice('sorg')*1.24*Qpurch1('sorg') +
exrcprice('mil')*1.23*Qpurch1('mil')+exrcprice('maiz')*1.37*Qpurch1('maiz')+Cashtrans1 =l=
```

```
*Icap+ sum(crop $(ord(crop)gt 1),exrcprice(crop)*Qsale1(crop)) ;
Icap1+ sum(crop $(ord(crop)gt 1),exrcprice(crop)*Qsale1(crop)) ;

LANDCROP1.. sum(cropact$(not(ord(cropact)eq 4)),Xha(cropact))=L= Land1;
*Land constraint for millet
LANDCROP2..Xha('trdmi')=L= Land2;
INUSE(inp)..sum(cropact, inpuse(cropact,inp)*Xha(cropact))=E= totinp(inp);

FARMLABAV(lper)..sum(cropact,labusec(cropact,lper)*Xha(cropact)) =l=
sum(labor,labavail(labor,lper)*farmlab(labor))+ Hlab(lper);

positive variable borrow(t,ty);
*Constraints for the second period (End of December-May)

GRAINBAL2(crop,t,ty)$((ord(crop)gt 1)and(sy(t)))..cons2(crop,t,ty)+ Qsale2(crop,t,ty)+
Qtrans2(crop,t,ty) =l=
 Qtrans1(crop)+agprod(t,crop)+ Qpurch2(crop,t,ty);

APROD(crop,t)$sy(t).. agprod(t,crop)=E=
sum(cropact,outmap(cropact,crop)*yield(t,cropact)*Xha(cropact));


GRAINCONS2(t,ty)$sy(t)..sum((crop)$(ord(crop)gt 1),cons2(crop,t,ty))=G=mincons2;

CASHBAL2(t,ty)$sy(t).. hhexp2 + hprice(t,ty,'mil')*1.38*Qpurch2('mil',t,ty)+ hprice(t,ty,'sorg')
 *1.39*Qpurch2('sorg',t,ty)+ hprice(t,ty,'maiz')*1.40*Qpurch2('maiz',t,ty)+Cashtrans2(t,ty)
+ sum(lper,Hlab(lper)*hirew(lper))+sum((cropact)$(ord(cropact)lt 3),sum((inp)$(ord(inp)lt 8),
Xha(cropact)*inpuse(cropact,inp)*incost(inp)))=l=
 hprice(t,ty,'mil')*Qsale2('mil',t,ty)+ hprice(t,ty,'sorg')*Qsale2('sorg',t,ty)+
hprice(t,ty,'maiz')*Qsale2('maiz',t,ty)+ Cashtrans1+pricecot*agprod(t,'cot')  ;

*Harvest income requirement
HARVINC(t,ty)$sy(t)..hprice(t,ty,'mil')*Qsale2('mil',t,ty)+ hprice(t,ty,'sorg')*Qsale2('sorg',t,ty)+
hprice(t,ty,'maiz')*Qsale2('maiz',t,ty)+ pricecot*agprod(t,'cot') =G= harvreq;

COTONCRED(t)$sy(t)..pricecot*agprod(t,'cot') =G= sum((cropact)$(ord(cropact)lt
3),sum((inp)$(ord(inp)lt 8), Xha(cropact)*inpuse(cropact,inp)*incost(inp)));

LIMPURCH2(crop,t,ty)$((ord(crop)gt 1)and(sy(t)))..Qpurch2(crop,t,ty) =L= cons2(crop,t,ty)-
Qtrans1(crop);
*Constraints of the third period (End of May-September)

GRAINBAL3(grain,t,ty1,ty2)$sy(t).. cons3(grain,t,ty1,ty2)+ Qsale3(grain,t,ty1,ty2)
 + Qtrans3(grain,t,ty1,ty2) =l= Qtrans2(grain,t,ty1)+ Qpurch3(grain,t,ty1,ty2);

GRAINCONS3(t,ty1,ty2)$sy(t)..sum(grain,cons3(grain,t,ty1,ty2)) =G= mincons3;

CASHBAL3(t,ty1,ty2)$sy(t).. hhexp3 + Cashtrans3(t,ty1,ty2)+ rprice(t,ty1,ty2,'mil')
```

```
 *1.22*Qpurch3('mil',t,ty1,ty2)+ rprice(t,ty1,ty2,'sorg')*1.23*Qpurch3('sorg',t,ty1,ty2)+
rprice(t,ty1,ty2,'maiz')
 *1.27*Qpurch3('maiz',t,ty1,ty2)+ 1.12*(sum((cropact)$(ord(cropact)eq 5),sum((inp)$(ord(inp)gt
10), Xha(cropact)*inpuse(cropact,inp)*incost(inp))))
   =l= sum(grain,rprice(t,ty1,ty2,grain)*Qsale3(grain,t,ty1,ty2))+ Cashtrans2(t,ty1) ;


NTSOCRED(t,ty1,ty2)$sy(t)..rprice(t,ty1,ty2,'sorg')*agprod(t,'sorg') =G=
sum((cropact)$(ord(cropact)eq 5),sum((inp)$(ord(inp)gt 10),
Xha(cropact)*inpuse(cropact,inp)*incost(inp)));


GRINK.. sum((cropact)$(ord(cropact)eq 5),sum((inp)$(ord(inp)gt
10),Xha(cropact)*inpuse(cropact,inp)*incost(inp)))=L=socred;

*Expected profit


OBJECTIVE.. Eprofit =E= sum(t$sy(t),sum(ty1,sum(ty2,sum(ty3, huprice(t,ty1,ty2,ty3,'prob')
 *(sum(grain,huprice(t,ty1,ty2,ty3,grain)*Qtrans3(grain,t,ty1,ty2))+Cashtrans3(t,ty1,ty2))))));

Model Expprofit
/GRAINBAL1,  CASHBAL1, LANDCROP1, LANDCROP2,INUSE, FARMLABAV,
GRAINBAL2, APROD, CASHBAL2, GRAINBAL3,
HARVINC,
COTONCRED,
GRINK ,
LIMPURCH2,
NTSOCRED,
CASHBAL3, OBJECTIVE,
GRAINCONS1, GRAINCONS2, GRAINCONS3/ ;
cashtrans3.up(sy,ty1,ty2) = 10000000 ;
qtrans3.up(grain,sy,ty1,ty2) = 1000000 ;

*Qsale3.fx(grain,sy,ty1,ty2)=0;
Qsale3.fx('maiz',sy,ty1,ty2)=0;
Qsale3.fx('mil',sy,ty1,ty2)=0;
xha.fx('ntso') = 0 ;
*Solve Expprofit using lp minimizing icap ;
*Qsale3.fx('sorg',t,ty1,ty2)=0;

Solve Expprofit using lp maximizing Eprofit ;
```

VITA

# VITA

Jeanne Coulibaly Yekeleya is a citizen of the Republic of Cote d'Ivoire in West Africa. She holds a doctorate in Veterinay Sciences and Medicine from the University of Cheikh Antah Diop in Dakar, Senegal in 2000. She then worked as a Program Officer in the Ministry of Agricultural and Livestock Resources in Cote d'Ivoire for four years. In 2005, she was granted a Fulbright scholarship for a Master's in Agricultural Economics at Purdue University. She concentrated for her master's thesis on the demand and supply of dairy products in Cote d'Ivoire. An article from her master's research has been published in the "Journal of Agricultural Trade and Development", in 2007. After the master's she joined the Ph D program at Purdue as a research assistant. Her research assistantship focuses on agricultural technology adoption, marketing strategies and women's welfare.