AGRICULTURAL ECONOMICS

Agricultural Economics 46 (2015) 53–67

Will cotton make a comeback in Mali?

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Received 2 May 2013; received in revised form 24 June 2014; accepted 30 July 2014

Abstract

With the decline of cotton especially in the marginal cotton areas, farmers have been using more of the cotton-financed inputs on the cereals. The cotton para-statal company (CMDT) has made a virtue out of this recommending diversification for these regions. Following the world price spike in 2010, the Malian government responded with a substantial price increase for cotton in 2011 of 38% to rejuvenate the Malian sector. This article looks at the impact of this price policy in the cotton economy and the potential of new cereal technology and marketing strategy to raise incomes and facilitate the diversification. Given the importance of the marketing decision of selling later after the recovery of cereal prices from the harvest collapse, a discrete stochastic programming model was developed for three-stage decision making. Then, the recent changes in the cotton economy and government fertilizer subsidies were analyzed along with the introduction of the new technology marketing of sorghum. Cotton and maize continue to dominate the economy but the combined sorghum technology marketing increases farmers' incomes by 16% to 21% and eases the return to normal cotton prices, after the 2011 price spike, as well as the removal of the fertilizer subsidies.

JEL classifications: D81, O38, Q13, Q16, Q18

Keywords: Agricultural technology; Cotton; Sorghum; Marketing strategies; Government policy; Discrete stochastic model; Farm income; Mali

1. Introduction

Since the 1950s, cotton has been the main foreign exchange earner of Mali and several other West African countries (Burkina Faso, Chad, and Benin). Cotton has been called "white gold." However, in Mali, real cotton prices have declined in the 21st Century. As a result, cotton area and production have also declined steadily in the cotton areas especially outside the prime production regions. There, the combination of both declining cotton prices and cotton yields has encouraged Malian farmers to shift from cotton to cereal production.

Over the decade of 2000–2010, farmers diversified away from cotton and increased land area and inputs (Fig. 1) allocated to the cereals. An increasing fraction of fertilizer allocated as credit for cotton has been diverted to cereals, especially maize but also including sorghum. The Malian para-statal cotton company, "Compagnie Malienne pour le Développement du Textile" (CMDT; CMDT, 2011), responsible for the cotton sector has been touting these shifts as successes in encouraging diversification. However, a fundamental problem with cereal production in sub-Saharan Africa is the price collapses at harvest and in good weather. Those price collapses reduce the profitability of intensification. Strategic marketing especially avoiding harvest sales with storage can improve the income prospects for cereals.

The choice facing Malian policy makers is whether to attempt to recover cotton area and arrest the yield declines in cotton or to facilitate the shift to improved cereal technologies associated with strategic marketing or both. Facilitating diversification can also mean not giving targeted subsidies or other preferential treatments to cotton. Typically, the primary commodity has built up its own domestic, and in this case international lobby with substantial influence over supporting agricultural policy (Bingen, 1998). The historic success of a primary crop is similar to the Dutch disease in that it can encourage governments to neglect potential income-enhancing opportunities provided by diversification into new technology for alternative activities and to continue preferential and expensive policy measures to maintain the dominance of the primary crop. Investments in new agricultural technologies provide opportunities to consider a broad range of crop alternatives rather than maintaining a focus on supportive policy for cotton.

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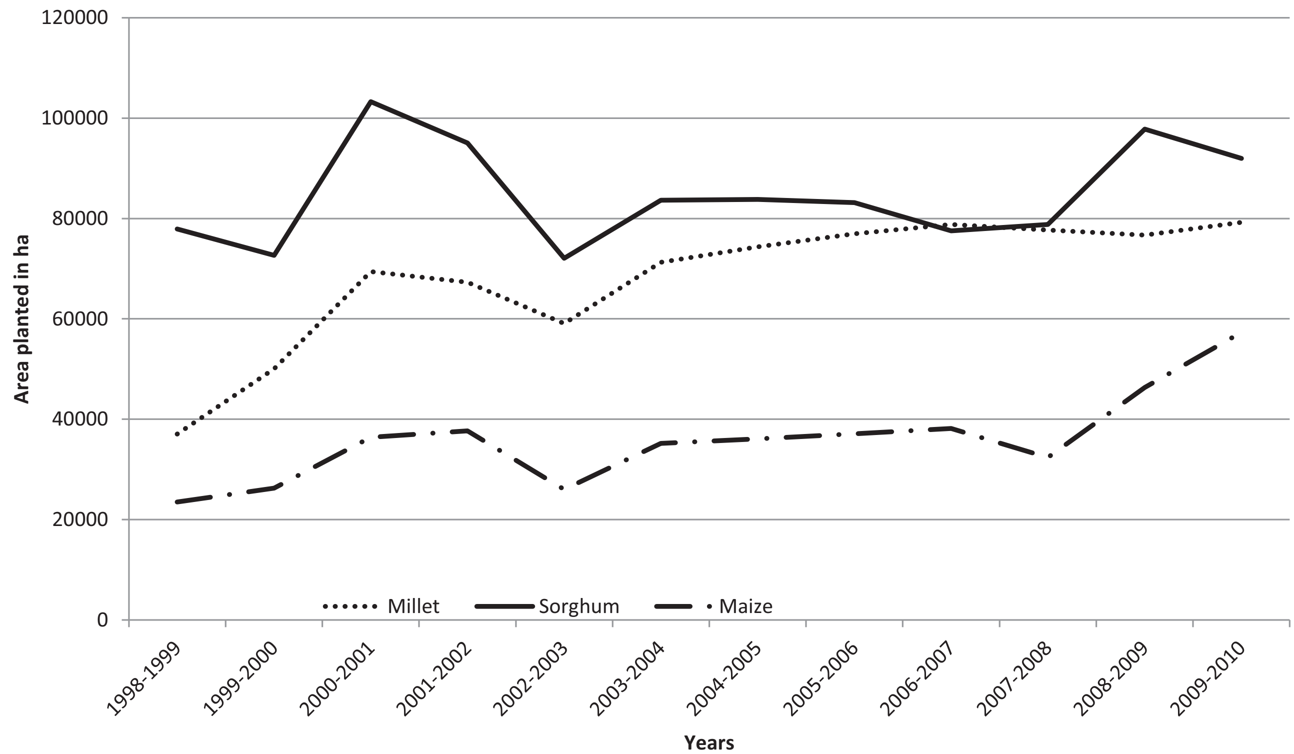
Data Appendix Available Online
A data appendix to replicate main results is available in the online version of this article.

 DOI: 10.1111/agec.12140



Source: Adapted from the Malian Ministry of Agriculture, 2010 in Coulibaly, 2011, p. 9.

Fig. 1. Area planted to sorghum, millet, and maize from 1998 to 2008 in the Koutiala region.

The objective of this article is to provide an assessment of the efficacy of alternative government policies to increase household incomes in southern Mali including the introduction of new production technology and marketing strategies for cereals and the recent introduction of fertilizer subsidies.

The article is structured as follows. We discuss new cereal alternatives in the cotton sector including the new sorghum technology and marketing as well as maize marketing. Then, we develop a farm household model to compare the income effects of the policy measures including these new activities. This section is followed by a discussion of the model results. Finally, the conclusions and policy implications are presented in a final section.

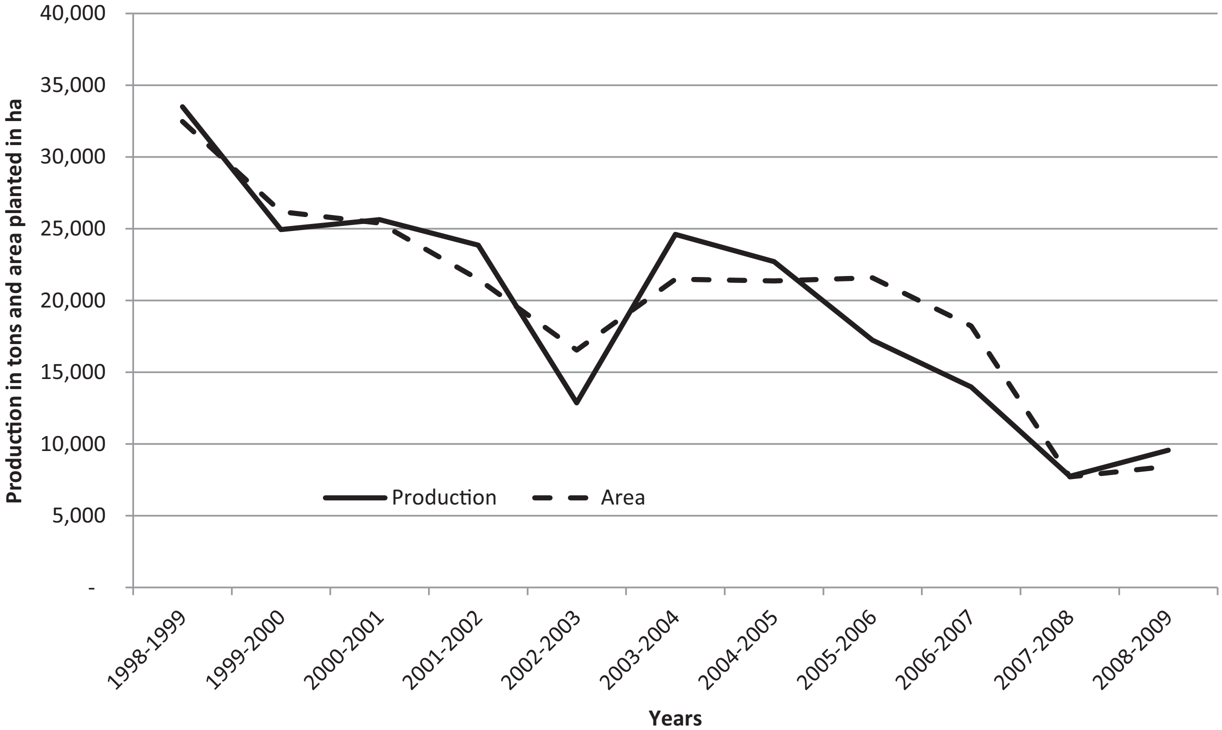
2. Decline of cotton with the rise of cereal technology and marketing innovations

The predominant cropping system in the prime cotton zone of Mali is a rotation of cotton–maize–sorghum with most of the purchased inputs applied to the cotton and maize and with sorghum obtaining some residual carryover effect from the fertilization. In the more marginal cotton regions, sorghum has a larger crop area than maize due to sorghum's greater tolerance of low rainfall and poor soil fertility (Fig. 1).

In the last decade, cotton area in the Koutiala region has declined dramatically by 80%, in sharp contrast with the area increase for cereals (Fig. 2). These changes have been attributed to poor soil fertility and delayed payments to farmers for cotton, but primarily to the declining cotton prices (Baquedano et al. 2010). The decline in cotton prices has been triggered by a lack of competitiveness in the international market with Bt transgenic cotton due to higher costs of insect control (Vitale et al., 2007) and the competition with synthetic fibers (Droy, 2008). With the floods in China in 2010, the international price for cotton increased by 80%. The subsequent domestic response in Mali was to increase the domestic cotton price by 38% in 2011.[1] So, we will be considering what happens as cotton prices decline from their 2011–2013 peak in Mali.

New cultivars of sorghum have been produced on research stations in the region over the past two decades. The principal physical constraint impeding the more rapid diffusion of the new sorghum cultivars has been low soil fertility (Vitale and Sanders, 2005). Besides the soil fertility problem, another substantial problem is the price collapse at harvest and in good and sometimes even normal rainfall (for further discussions, see Ouendeba, 2003 and Abdoulaye and Sanders, 2006). By employing storage, farming associations and sale after the postharvest price recovery, farmers can increase the profitability of the

[1] In 2011, the Malian cotton price was increased to 255 F CFA/kg from the 185 F CFA/kg in 2010. The exchange rate then (May 2011) was 452 F CFA/$. Note that world cotton prices quickly fell again in 2012. Mali kept the nominal prices Mali only lowering the farm gate cotton to 250 F CFA/kg in 2013, a 2% decline (USDA, 2013).



Source: Adapted from the Malian Ministry of Agriculture, 2010 in Coulibaly, 2011, p. 8.

Fig. 2. Cotton area and production in the Koutiala region (Mali) from 1998 to 2008.

increased expenditures on fertilizer (Coulibaly, 2011; see the seasonal price variation for different years in Fig. 3).

If the grain from the new sorghum technology with fertilization is sold at harvest, there is no income gain compared with the traditional sorghum variety and low input use (Table 1). Even with the fertilizer subsidy, this new activity sold at harvest is only slightly more profitable than the traditional activity. However, if the new sorghum technology with its higher yields is sold later, then substantially more profit is earned than with the traditional sorghum technology.[2]

Then, the profitability of the other two principal crops, cotton and maize, is calculated with and without the fertilizer subsidies. For cotton, two prices are considered, the very high price in 2011 and the expected price after the spike using an average of the cotton prices from 2006 to 2010 adjusted for inflation. Cotton prices are set by the government at around the start of the crop year. Cereal prices are market-determined. The maize price tends to be slightly less than the sorghum price.

Sorghum without the fertilizer subsidy but with improved marketing is more profitable than maize either with or without the maize fertilizer subsidies. The maize input costs are much higher than those of sorghum as the fertility demands are greater for maize. The cotton activity still dominates the cereals even without fertilizer subsidies for cotton (Table 1). However, note that the omission of labor costs in the gross margin estimation biases these results. Cotton is by far the most labor-intensive with repeated sprayings and large harvest labor requirements. So, we need to make comparisons of these activities in a framework which takes into account labor costs (family and hired) such as a programming model.

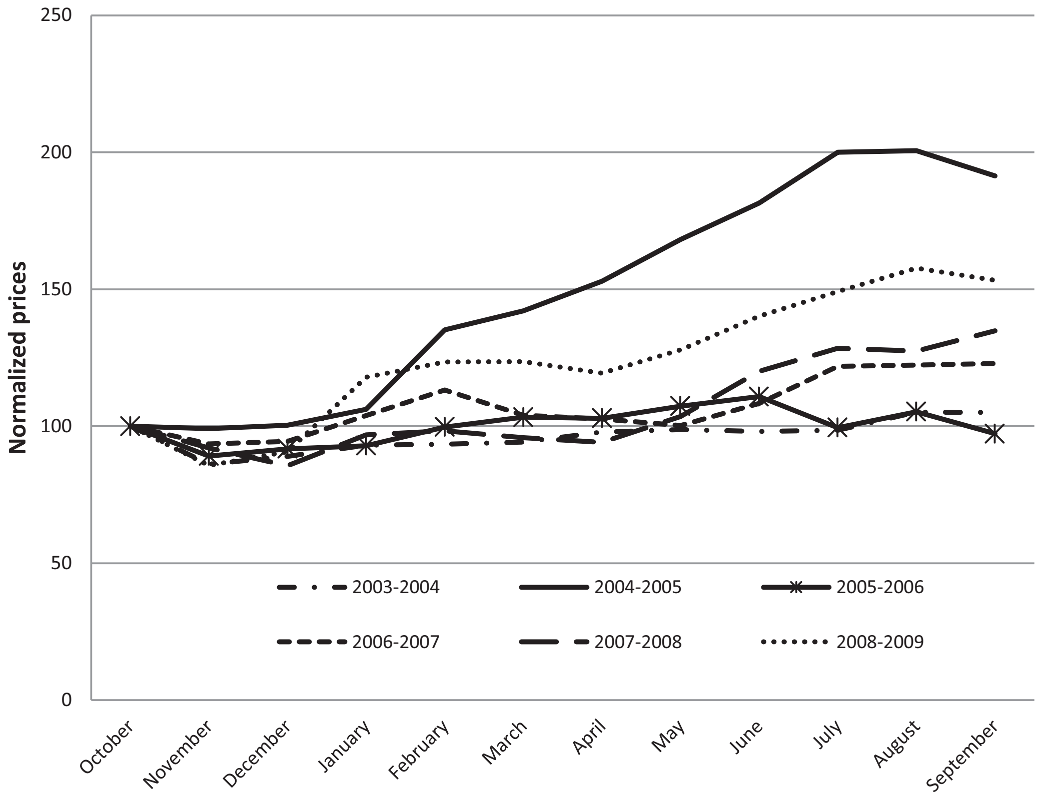
3. Modeling the technology-marketing decisions at the farm

Evaluating new technologies in a risky environment has generally been approached with some variation of an expected utility model (Abdoulaye and Sanders, 2006; Ghadim and Pannell, 1999; Marra and Carlson, 1990). In these models, multiple states of nature and the incorporation of the risk aversion characteristics of the decision maker have been a central focus. Decisions are made at one point of time (typically planting time), and there has been a focus on yields and weather risks.

The marketing decisions, especially the response to the price collapse at harvest, are important for profitability of the sorghum technology. Hence, the model used here focuses on decisions at several points in time during the crop season, and reflects the dynamic relationships between the yields and prices.

The Discrete Stochastic Programming (DSP) model has been used for analyzing farmers' sequential decision making under uncertainty. Cocks (1968) developed a multistage

[2] With the lower yields, the traditional sorghum technology only provides for home consumption. With the new technology, the later sales, storage, and sales through a farmers' association become important.



Source: Coulibaly, 2011, p. 32.

Fig. 3. Sorghum prices in Koutiala, 2003–2009.

farming model in which labor requirements and gross margin are stochastic decision variables with discrete probability distributions. Rae (1971) further elaborated the capability of DSP in solving problems with sequential decisions under uncertainty. 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. Lopez-Pereira et al. (1994) determined the income effects of soil conservation strategies and seed–fertilizer technologies in Honduras by employing 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 postharvest seasons. A common feature across these studies is that rainfall and/or yields were the only random variables influencing farmers' decisions. The models did not incorporate randomness in prices. Yet, variability of harvest and postharvest prices are also important sources of uncertainty influencing farmers' decision making.

This study takes into account dynamic price uncertainties as well as yield variability in analyzing farmers' production, inventory, and marketing decisions over time. Conditional strategies allow future decisions to be influenced by past decisions (Preckel, 2008). Moreover, randomness in the constraint parameters is also incorporated.

The timeline that illustrates the process of farmers' decision making is represented in Fig. 4

Our model is presented below in algebraic notation

$$\text{Max } E[W] = \sum_s \sum_t \sum_r \rho_{str} W_{str} \tag{1}$$

subject to

$$-A_1 X_1 + B_{1s} X_{2s} \leq b_1 \tag{2}$$

$$-A_{2s} X_{2s} + B_{2st} X_{3st} \leq b_2 \tag{3}$$

$$-A_{3st} X_{3st} + B_{3str} W_{str} \leq b_3 \tag{4}$$

$$X_1, X_{2s}, X_{3st}, W_{str} \geq 0 \tag{5}$$

where:

s, t, and *r* = the states of nature in stage 1, 2, and 3, respectively;

ρ_{str} = the joint probability of states *s*, *t*, and *r* occurring in stages 1, 2, and 3, respectively;

A_1 = a matrix of coefficients for stage 1 accounting relationships (sources for grains, factors of production, variable inputs, and cash);

Table 1
Returns to the traditional and new sorghum cultivars, with and without fertilizer subsidies in F CFA/ha

Inputs (F CFA/ha)	Traditional sorghum Cultivar	New sorghum cultivar No fertilizer subsidy	New sorghum cultivar Fertilizer subsidy	Maize cultivar No fertilizer subsidy	Maize cultivar Fertilizer subsidy	Cotton cultivar No fertilizer subsidy Average price	Cotton cultivar Fertilizer subsidy Premium price
Seed	1200	3000	3000	8000	8000	1035	1035
NPK	0	36000	25000	36000	25000	55350	37500
Urea	0	19000	12500	38000	25000	19000	12500
Herbicide	0	0	0	9000	9000	13500	13500
Insecticide	0	0	0	0	0	22550	22550
Total input costs	1200	58000	40500	91000	67000	111435	87085
Yields kg/ha	1154	1642	1642	1750	1750	1280	1280
Harvest price (F CFA/kg	85	85	85	80	80	180	231
Total revenue (F CFA/ha)	98,090	139,570	139,570	140,000	140,000	230400	295680
Gross margin	96,890	81,570	99,070	49,000	73,000	118965	208695
Price in recovery period (F CFA/ha)	na	115	115	110	110	na	na
Total revenue (F CFA/ha)	na	188,830	188,830	192,500	192,500	na	na
Storage costs	na	4,105	4,105	4,375	4,375	na	na
Gross margin (F CFA/ha)	na	126,725	144,225	97,125	121,125	na	na

Notes: All data are in 2008 F CFA. This was a normal rainfall year. Yield data are from 2008 farm interviews in 2011Coulibaly, 2011. The fertilizer subsidies for sorghum and the cotton price increase only occurred in 2011 but these were discounted to the 2008 prices. Cotton price increased to 255 F CFA in 2011 responding to the 80% world price increase in 2010. Secondary cereal prices are from local market so there is an adjustment for transportation costs to the market of 50 F CFA/100 kg sack. Storage costs are calculated (interest and depreciation) based upon a study of this type of inventory credit (Baquedano et al., 2010). Note also that with the new sorghum a surplus is produced and sold later in the year and with the traditional sorghum, grain is basically for home consumption.
Source: Calculated from 2008 interviews. For details, see Coulibaly, 2011, p. 27.

B_{1s} = a matrix of coefficients for stage 1 accounting relationships, conditional on the realized state of nature (s) in stage 1 (uses for inventories of grains, factors of production, variable inputs, cash, and consumption);

b_1 = a vector of endowments in stage 1 (initial stocks of grains, factors of production, cash, and minimum consumption quantities);

X_1 = stage 1 decision variables (land allocation, purchases of inputs, grain sales and purchases);

A_{2s} = a matrix of coefficients accounting relationships conditional on realization of state of nature (s) for stage 1 (sources for grains and cash);

B_{2st} = a matrix of coefficients for stage 2 accounting relationships, conditional on the realized states of nature (s and t) in stages 1 and 2 (uses for inventories of grains and cash);

b_2 = a vector of endowments in stage 2 (cash obligations and minimum consumption quantities);

X_{2s} = decision variables conditional on realization of state of nature (s) for stage 2 (grain sales, purchases, and storage);

A_{3st} = a matrix of coefficients accounting relationships conditional on realization of state of nature (s) for stage 2 (sources for inventories of grains and cash);

B_{3str} = a matrix of coefficients for stage 1 accounting relationships, conditional on the realized states of nature (s and t) in stages 1 and 2 (uses for inventories of grains and cash);

X_{3st} = decision variables conditional on realization of state of nature (s and t) for stage 1 and 2, respectively (grain sales, purchases, and storage);

b_3 = a vector of endowments in stage 3 (minimum consumption quantities); and

W_{str} = end period wealth conditional on realization of states of nature (s, t, and r) in stages 1, 2, and 3, respectively.

Equation (1) denotes the expected end period wealth objective, where the expectation is taken over the states of nature s, t, and r. The model time horizon goes from one planting season to the beginning of the next growing season as depicted in Fig. 4 The state (s) represents the state of nature of yield and price at harvest, t is the state of nature defining the price change between harvest and the second planting, and r captures the

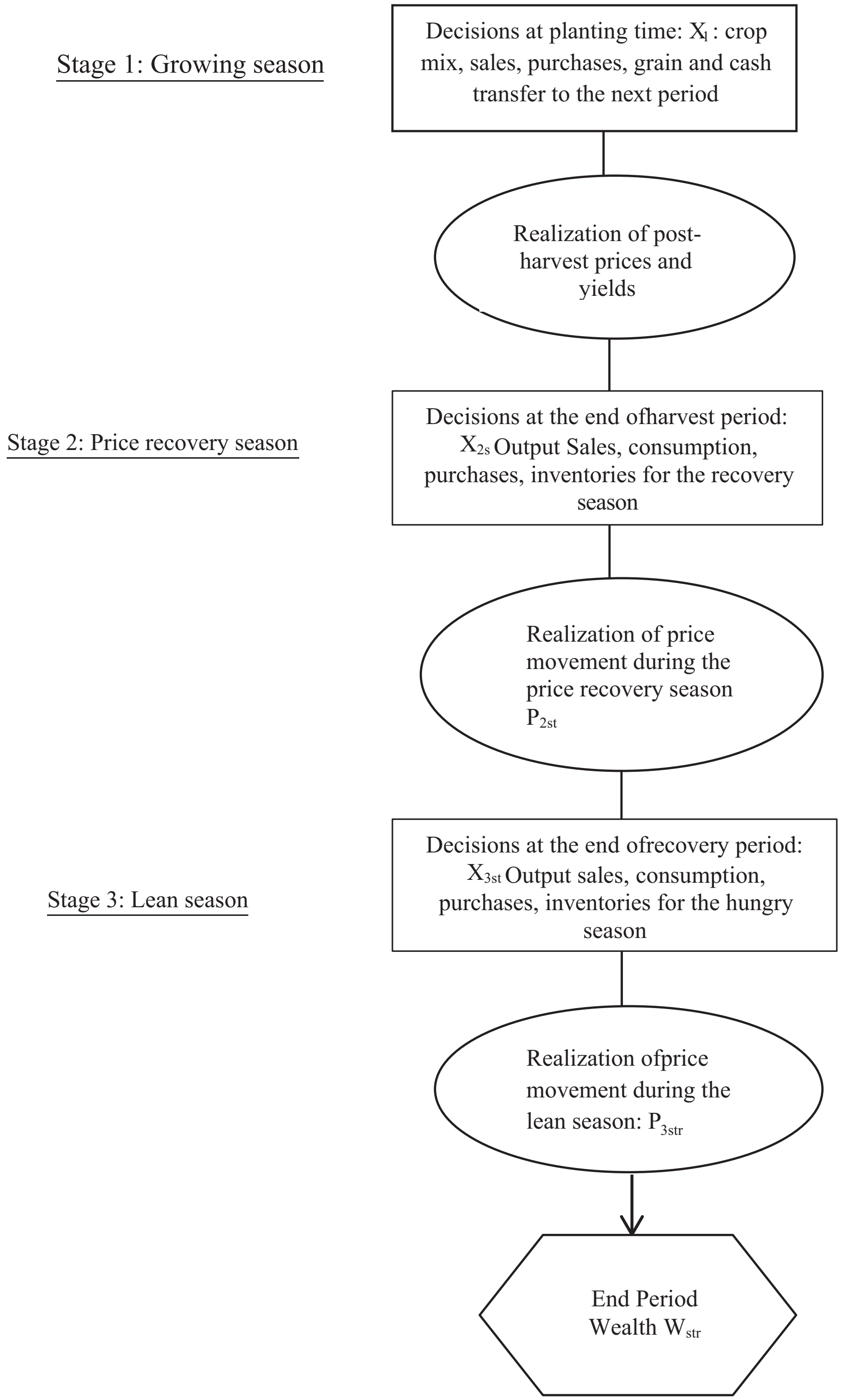


Fig. 4. Timeline of the discrete stochastic model for farmers' decision making in Mali.

state of nature defining the change in prices between the second and third stages. Equation (2) denotes stage 1 constraints that account for sources and uses (conditional on state [*s*] to account for potential variation in the use of inventories in the next stage) of resources (land, labor, purchased inputs, grain stocks, and cash). Stage 1 starts at the beginning of the first growing season in June, and ends at harvest in December. Stage 1 decisions encompass land area allocation for crops (maize, cotton, sorghum ,and millet), quantity of fertilizer and seeds to use, amount of labor to hire, grain consumption, quantity of grains purchased and sold, and cash retained for next period. These decisions are constrained by resource availability as well as the future needs for cash and consumption. Initial capital comes from the earnings of the previous season from cereals, cotton, and other enterprises.

Equation (3) denotes stage 2 constraints, conditional on states (*s* and *t*) that account for sources and uses of resources (grain stocks and cash). These constraints include a minimum consumption requirement for the three main grains, sorghum, millet, and maize, with a total of 5,103 kg in the initial stage. This is observed consumption during the farm household interviews in 2008, a normal crop year, and is constant across states of nature.

The second stage spans the months of January through May. At the end of the growing season, January, the crop yields and grain prices are known. These outcomes will help determine the consumption and expenditure decisions at harvest conditional on the realized yields and harvest time prices, and based on conditional distributions of the further evolution of prices over time.

Thus, conditional on the yield and price outcomes and their knowledge of the future, farmers decide on the amount of crops to sell at harvest. Farmers also have the alternative to store cereals for consumption, and buy/sell later in the year after the storage has taken place. These decisions are constrained by the state of nature of crop production determining the amount of grain that they have in storage. At that point, the value of cotton production is used to reimburse the in-kind fertilizer credit received from the cotton para-statal company.[3]

These constraints also reflect a harvest income constraint. Farmers need to insure that at harvest there is sufficient income to pay for a series of obligations traditionally incurred then. These expenditures include paying the costs incurred during the planting season for hired and family labor, schooling costs, costs of naming ceremonies and weddings, and deferred medical and housing expenditures. The cash constraint at harvest insures that there is enough cash from sales of crops at harvest to cover those expenditures.[4] Again, as in the first stage, the quantity of grain consumption (of sorghum, millet, and maize) has been collected during the household interviews and is estimated at 3,645 kg for the second stage.

Equation (4) denotes stage 3 constraints, conditional on realization of states *s*, *t*, and *r*, that account for sources and uses of resources (grain stocks and cash). The third stage extends from the planting in June of the second growing season to September.[5] At the end of the price recovery season, farmers know postharvest grain prices. At this point, they make decisions regarding grain sales and purchases with knowledge of current grain inventories and prices (both conditional on past actions and realizations of yields and harvest time prices), and with knowledge of the conditional distribution of future price movements (see Appendix A).

At the end of the time period, farmers sell all remaining stocks of grain, valued at the realized grain prices at the end of the planning horizon. Constraints include the grain consumption requirement for the third stage estimated at 2,916 kg from field interviews. Constraints include an accounting relationship for the net returns earned from the activities performed across periods under the joint events (states of nature *s*, *t*, and *r*) and the value of the remaining stocks at the end of the planning horizon. The *Wstr* is equal to the end period wealth, the expected value of which is maximized in the objective function.

Finally, Eq. (5) represents the non-negativity constraints on the decision variables.

Within the model, we are treating risk aversion the way farmers say that they behave (Coulibaly, 2010). Rather than using the conventional method of introducing a utility function reflecting risk aversion, our technique is to identify farmers' stated objectives and to use them as the constraints before maximizing expected income. Two constraints are frequently stated by farmers (Baquedano et al., 2010) and utilized here. The first requirement is that harvest time income is sufficient to pay for a series of obligations traditionally incurred then. Second, farmers are required to put aside sufficient grain for consumption during at least part of the rest of the year.[6] At all decision points, a fixed subsistence constraint specifying a minimum grain consumption quantity has been defined. This minimum grain consumption requirement is met either by own production or by purchases from the market. These two requirements for household income at harvest and for subsistence are primary methods of farmers for coping with the riskiness of their production and marketing environment; Farmers are modeled as maximizers of their net income subject to first satisfying these constraints on required harvest time expenditures and home consumption.

4. Estimation of the stochastic process

A fundamental step in a DSP model is to develop a model of the stochastic process governing yields and prices over time. In the DSP, decisions are made at three different points of time: planting, harvest, and sale several months after the harvest time price collapse (see Fig. 4).

The sequential nature of the decisions in the DSP model takes into account the random variables that have been realized in the past, the decisions that have been made in the past, and the conditional distribution of random variables whose outcomes will be realized in the future. For example, at harvest crop yields and prices have been realized but the changes in prices during the storage period have not been realized—only their conditional distributions are known.

[3] In the last five years, CMDT has made loans for maize and sorghum input credits with the provision that the loans must be repaid in cotton.

[4] Cotton revenues are received several months after harvest when the cotton is picked up. Moreover, in recent years there have been delays of cotton payments into the summer, another reason for farmer dissatisfaction.

[5] Note that this second planting decision is not modeled. In this third stage another marketing decision is made and we estimated end period wealth.

[6] Due to storage problems, such as insects or lack of storage capacity, farmers often do not attempt to store cereals until the next harvest.

The joint distribution of yields is implemented via an empirical distribution. This distribution is representative of the entire sample of yields and prices and gives an equal probability of occurrence to each element or state of nature in the sample. So, this distribution retains the full information in the sample regarding not only the means and covariances between yields, but also the higher-order moments (skewness, kurtosis, etc.). For yields, 29 states of nature are captured in the empirical distribution with a probability of realization of 1/29 for each state. An alternative distribution could have been the normal distribution but the normality of yields has been challenged by numerous studies (Just and Weninger, 1999; Nelson and Preckel, 1989; Ramirez et al., 2003).

Because the yield time series data has a longer sequence of observations than the price time series, a direct empirical joint distribution is not available. To deal with this, harvest prices (i.e., prices that are realized in tandem with yields) are regressed on yields using ordinary least squares. These predictive equations are used to obtain a mean level for the price of each commodity at harvest. To obtain a joint distribution of harvest prices conditional on realized yields, the empirical distribution of errors from these regressions is used to construct states of nature for realized harvest prices with equal probability of realization.

Similarly, the distributions of prices for the later periods in the model (where grain may be sold after storage) are regressed on the previous period's prices. Again, the regression models provide the means for the distributions of prices. The residuals from the estimations are added to those means to obtain conditional distributions of prices, given the realizations of past prices and yields. Details of the estimations of the price dynamics models and for the yield distributions are found in Appendices A and B, respectively.

5. Data

Close to the beginning of the growing season, the yearly price of cotton at which the cotton company will buy cotton from farmers is announced. Input credits for cotton and fertilizers for the cereals are received from the para-statal cotton company to be repaid in cotton. Other mean harvest time prices are estimated as functions of yields for the cereals. Then, mean prices in succeeding periods are estimated as functions of prices in the previous period (see Appendix A). As indicated in the previous section, the distributions of errors from the regressions are added to the estimated conditional means to obtain conditional distributions of prices.

The data used to build the model were assembled from a combination of primary and secondary sources. Primary data have been collected from field surveys conducted in 2008 and supplemented by additional field research in June and July 2010 in the village of Garasso of the Koutiala District (Coulibaly, 2011). A random sample of 67 farmers of comparable assets and endowments were interviewed and the average of this sample was selected to be a representative farm for the analysis. Primary data collected included household expenditures, grain consumption requirements, stocks of grain at the beginning of the growing season, initial capital available for the agricultural activities, land available for cultivation, available farm family labor, costs and quantity of purchased inputs (fertilizer, pesticides, insecticides, seeds) necessary for the crop activities. These data were used as exogenous factors to specify the model parameters and the resource constraints that enter into Eqs. (2)–(4) The values of all these parameters are reported in Coulibaly (2011).

Secondary data were obtained at an aggregate level (i.e., collected at the district level) and include rainfall observations, yields, and prices for the crops analyzed (sorghum, millet, cotton, and maize). Yields were annual observations from 1998 to 2008 gathered at the Ministry of Agriculture in Mali and the CMDT. Rainfall observations in Koutiala for the time span of 1980 to 2009 have been collected from the Malian Department of Meteorology. Yield observations were utilized for the distribution of the yield states of nature (s) and the stochastic resource requirement mentioned in Eq. (3) Since yield data were only available for a set of 10 years and we needed a longer time frame for the estimated empirical distribution, the rainfall observations were used to predict yields for the years 1980 to 2009 (see Appendix B and Table B1). One year of observation (1984) was dropped because of inconsistency in the data. Hence, a total set of 29 observations composed of predicted and real aggregate yield served in the estimation of the probability distribution of yields. Yields for each crop were also incorporated in the model to estimate total production based on area allocation.

Price data for the grain crops maize, millet, and sorghum of the model were primarily over 1998 to 2008 and were obtained from the National Market Watch in Mali (see Tables A1–A3). These retail prices were adjusted by subtracting transportation costs to estimate farm gate prices over time with the assumption of constant margins. Farmers also sell in local and regional markets. Those prices have been deflated using a GDP index obtained from the International Monetary Fund. Nominal cotton prices were obtained from the CMDT and were converted to real prices (Table B1) using the GDP index.

6. Results

This is an agricultural system traditionally dominated by cotton so the reaction to the 2010 world price spike of cotton is shown. Then, the income effects of the new sorghum technology and marketing are estimated. Finally, as the cotton price returns to normal levels and the fertilizer subsidies are removed, the income effects and the role of new sorghum technology are evaluated.

In the present system, traditional sorghum production is the predominant activity as cotton prices have been falling over the last decade and maize needs high fertilization levels (base case;

Table 2
Farm incomes and crop allocations with normal and peak cotton prices with farmers' sorghum technologies presently in the field and the improved marketing strategies for cereals

	Base case Base cotton price Sale of cereal at harvest	Scenario 1 Peak cotton price Sale of cereal at harvest	Scenario 2 Peak cotton price Storage and late sale
Cotton price (CFA/kg)	185	231	231
Cotton area (ha)	3.84	5.48	5.48
		43%	43%
Maize area (ha)	1.28	5.68	5.68
		344%	344%
Traditional sorghum (ha)	6.9	0.84	0.84
		−88%	−88%
Millet area (ha)	3	3	3
Total area	15	15	15
Income (×1000 CFA)	635	1,118	1,169
		76%	84%

Notes: Income is end period wealth in this model. Fertilizer subsides on cotton, maize, and sorghum.
Exchange rate: $US1 = 452.61 F CFA on April 18, 2011 at www.oanda.com.
Millet area has been fixed at 3 ha since millet is usually grown on the lower soil fertility areas of the farm.
Source: Calculated from Coulibaly, 2011.

Table 2). In 2011, CMDT responded to the increased world cotton prices of 2010 with a 38% price increase. Cotton and maize areas substantially increased with incomes increasing 76% (scenario 1, Table 2). When cotton prices are higher, farmers can obtain more input credits especially for inorganic fertilizers and farmers often use some of this fertilizer on the cereals. Note that maize area increases as traditional sorghum area collapses. If the maize is stored and sold later, there is a further increase in incomes and maize area (scenario 2, Table 2).

Now, we introduce the improved sorghum technology consisting of a higher-yielding cultivar of sorghum, use of moderate levels of inorganic fertilizer, and improved agronomic methods.[7] The estimated sorghum yield increase was 42% from the 1,154 kg/ha of traditional sorghum (with the residual fertilizer effect from fertilizing cotton) to 1,642 kg/ha (see Table 1).[8]

In 2011, besides the high price for cotton there were also fertilizer subsidies on cotton, maize, and sorghum;[9] so this is the base case for Table 3. With the new sorghum technologies, income is increased by 10% (scenario 2, Table 3). Traditional sorghum disappears and maize area is substantially decreased. Even cotton area slightly decreases. Adding strategic marketing (scenario 3) raises incomes a further 11% (Table 3).

Nevertheless, at this very high cotton price (231 F CFA/kg), cotton remains the dominant activity and helps both cereals by making input credits available (which are repaid in cotton).[10] Storage and later sale of grains (before the next planting) result in a 26% increase in prices from the harvest price (Fig. 4). With the later sales, there is a shift to cotton as the adverse effect of poor rainfall on maize yields offsets the higher profit potential of increased maize area (scenario 3, Table 3).

Whereas world prices came down rapidly during 2012–2013, Malian nominal prices for cotton stayed at the same nominal levels. The Malian cotton price increase of 2011 was only one-half the world price increase of 2010. Thereafter, world cotton prices fell to $1/lb and $0.88/lb, respectively, in 2012 and 2013 as compared to $1.65/lb in 2010. Hence, some continued decline in the Malian real cotton prices is expected. The inflation-adjusted mean price of the five years prior to 2011 for the price of cotton is then employed in the model as the adjusted cotton price after the decline.

Maintaining the fertilizer subsidies for all three major activities, the income decline from the return to normal cotton prices was only 8%. So, the sorghum technology-marketing introduction moderates this income decline (compare Tables 2 and 4). Moreover, here there is a net return increase of $0.73 to $1.44 for each one-dollar release of the credit constraint on the new sorghum activity. So, there is substantial encouragement for expansion of the new sorghum activity by making more credit available.

The fertilizer subsidies are a primary policy issue presently in Malian agriculture. The Malian fertilizer price peak was especially dramatic in 2008 but was followed one year later by a decline in the urea price and the subsidized prices for

[7] The moderate inorganic fertilizer dose utilized in the fieldwork was two 50 kg sacks of NPK and one sack of urea. The improved agronomy included organic fertilizer, ridging, side-dressing, the split application of fertilizer and thinning. After 2008, the recommended fertilizer dose has become one sack of DAP and one sack of urea. This reduces the input costs and concentrates on the common deficiencies of N and P in semiarid sub-Saharan Africa.

[8] There were 50 farmers following these improved practices in the farm-level work of Garasso. A total of 35 farmers were interviewed and these are the mean yields for the new cultivar of sorghum and the traditional sorghum on their farms. Crop cut average yields for the target group were 1.96 tons/ha and the highest yield was 3.4 tons/ha (See Coulibaly, 2011, p. 3).

[9] In 2011, the Malian government expanded the fertilizer subsidy to both sorghum and millet for certain regions. Regional changes are now made annually.

[10] Since 2010, input credits have been made for the new sorghum technology in the Koutiala region with repayment in sorghum to the large merchants and in cash by the merchants to the BNDA (development bank).

Table 3
Farm income and crop alternatives with new sorghum technologies (with fertilizer subsidy), peak cotton prices, and marketing strategy

	Base case Technologies presently adopted Harvest sale cereal	Scenario 2 New sorghum Technology Harvest sale cereal	Scenario 3 New sorghum Technology Storage & late sales
Peak cotton price (CFA/kg)	231	231	231
Cotton area (ha)	5.48	5.26	5.26
		−4%	−4%
Maize area (ha)	5.68	2.75	2.75
		−52%	−52%
Traditional sorghum (ha)	0.84	.	.
Millet area (ha)	3	3	3
Improved sorghum (ha)	0	4	4
Income (×1000 CFA)	1,118	1,233	1,294
		10%	16%
Marginal value of the improved sorghum credit constraint	0	0.43	0.66

Notes: Income is end period wealth in this model. Fertilizer subsides on cotton, maize, and sorghum. Exchange rate: $US1 = 452.61 F CFA on April 18, 2011 at. The cotlook index of world cotton price in 2010 was estimated at 164 cents/pound.
Source: Calculated from Coulibaly, 2011.

Table 4
Farm incomes and crop choices with normal cotton prices and alternative subsidy programs for fertilizer

	Base case	Scenario 4	Scenario 5	Scenario 6	Scenario 7
	Peak cotton price Storage & late sales Fertilizer subsidy	Normal cotton price Storage & late sales Fertilizer subsidy	Normal cotton price Storage & late sales Removal fertilizer subsidy	Normal cotton price Storage & late sales Subsidy only for maize and cotton	Normal cotton price Harvest sales Subsidy only for maize and cotton
Cotton price (CFA/kg)	231	212	212	212	212
Cotton area (ha)	5.26	4.57	4.74	4.97	5.42
		−13%	−10%	−6%	3%
Maize area (ha)	2.75	3.43	2.38	4.01	4.78
		25%	−13%	46%	74%
Traditional sorghum (ha)	.	0	1.86	0	1.79
Millet area (ha)	3	3	3	3	3
Improved sorghum (ha)	4	4	3.01	3.01	.
		0	−25%	−25%	
Income (×1000 CFA)	1,294	1,191	948	1,118	1,002
		−8%	−27%	−14%	−23%
Marginal value of the improved sorghum credit constraint	0.66	0.73	0.5	0.3	.

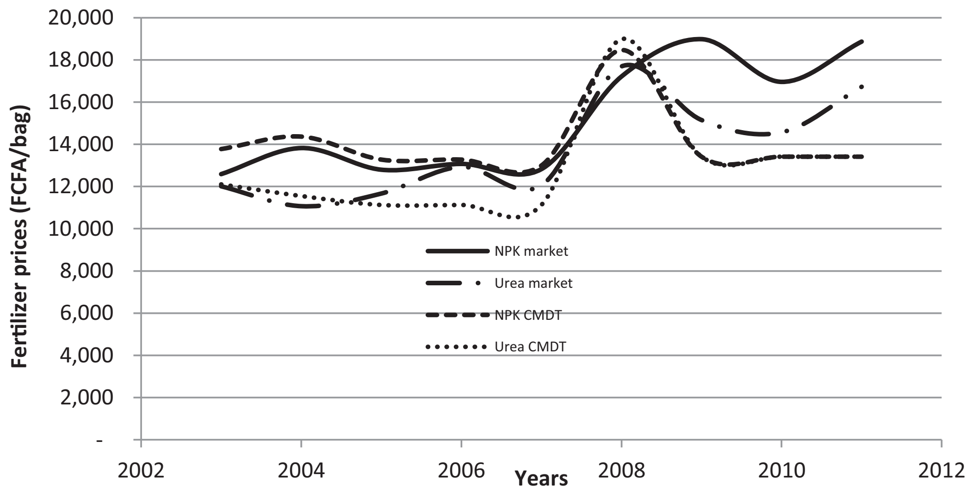
Notes: Income is end period wealth in this model. Fertilizer subsidies on cotton, maize, and sorghum. Exchange rate: $US1 = 452.61 F CFA on April 18, 2011 at www.oanda.com. The improved sorghum area ceiling of 4 ha is due to the limit on the credit amount provided to farmers. This credit can only allow them to grow a maximum of 4 ha. The normal price of 212 CFA/kg is the mean of real cotton prices (2008 base) for the last years (2006–2010) before the cotton spike.
Source: Calculated from Coulibaly, 2011.

the compound fertilizer and the urea made available by CMDT (Fig. 5). After a dip in fertilizer price in 2010 from the 2008 high, fertilizer prices again increased to 2008 levels in 2011. So, the subsidies have been very important in prices available to farmers.

The fertilizer price spikes could represent either temporary demand shifts[11] or long-term structural changes (Fig. 4, also Heffer and Prod'homme, 2011, 2012; Ott, 2012, p. 14). In the first case, the present high fertilizer prices result from poor weather conditions in major agricultural regions in the world and from the biofuel demand shift in the United States. In this case, the subsidized fertilizer prices are expected to approximate the long-run normal prices. Hence, cotton, maize, and new-technology sorghum retain an important place in the crop mix and incomes only decline by 8%, also including the return of cotton to its long-run expected prices (scenario 4, Table 4).

For the second case of a long-term structural shift with fertilizer prices at the high levels after 2008 and fertilizer subsidies removed, incomes fall 27% (scenario 5, Table 4). Traditional

[11] The observed price spikes are especially noticeable after bad weather years in major producers and in association with the push to use maize as biofuel in the United States.



Source: Estimated from CMDT, 2011.
Notes: After 2008, the subsidized prices of the compound fertilizer (NPKBS) and urea were identical. NPKBS refers to the chemical composition of the fertilizer with the macronutrients of nitrogen, phosphorous, and potassium and the micronutrients of boron and sulfur. The CMDT subsidizes the prices of fertilizer for cotton and maize and for sorghum and millet in certain regions of Mali in 2011.

Fig. 5. Market and CMDT prices for cotton fertilizer (NPKBS and urea) in Mali from 2002 to 2011.

sorghum experiences a sharp decline in area while the other fertilized activities of cotton, maize, and improved sorghum are less affected.

If the fertilizer subsidies are only allowed for cotton and maize but not for sorghum as was the case prior to 2011, incomes only decline by 14% with the fall in the cotton price. Note that when the fertilizer subsidy for sorghum is withdrawn, the improved sorghum area declines to 3 ha from 4 ha but retains an important role in the crop mix. Only when there is no storage for later sales does the new sorghum activity drop out of the crop mix (scenario 7, Table 4). Thus, the improved marketing has a larger area increase effect on the new sorghum technology than adding the fertilizer subsidy on sorghum. Cotton stays a key component of the crop mix even with lower prices and removing the fertilizer subsidies, but so does the new sorghum activity as long as better marketing is encouraged (Table 4).

7. Conclusion

With the abrupt decline of the cotton sector in the more marginal cotton zones during the last decade, the cotton parastatal (CMDT) and the government have been trying to encourage diversification focusing primarily on maize. Here, we have shown the potential of new sorghum technologies, including improved marketing, to provide moderate income gains even with the return of cotton to normal price levels and the removal of the fertilizer subsidies.

New sorghum technologies and strategic marketing facilitate some diversification away from cotton. This diversification also moderates income declines as the cotton price returns to normal levels and the fertilizer subsidies are eliminated. Nevertheless, these are small adjustments with the sorghum technology more of an addition to the cotton–maize system rather than a substitution of the cereals for cotton. However, it still seems also very important to proceed with diversification as Mali is expected to continue to lose export share to the cotton exporters utilizing Bt technologies (Vitale et al., 2007).

There are important learning by doing aspects of getting the moderate fertilizer levels employed and the rest of the agronomic practices[12] right to accompany the improved sorghum cultivar. Moreover, the subsidized fertilizer prices are probably closer to the long-run expected fertilizer prices[13] than the peak or spiked prices in Mali of 2008 and 2011 after adverse weather conditions in major production regions the previous years.[14]

In the Malian south, even in these more marginal cotton zones returns are higher for inorganic fertilizer on the cereals than in most of the country due to the higher rainfall. Hence, more progress could be made with cereals toward food security and for supplying the quantity of cereals necessary in feed for chickens and dairy cattle and substituting for millet

[12] This fertilizer needs to be side-dressed rather than broadcast and a series of agronomic practices need to be adopted. So, these changes have to be mastered by farmers to insure a high return to moderate fertilization (Coulibaly et al., 2011).

[13] This assumes that the fertilizer industry does not have the ability to maintain prices high even after the demand peak conditions. With all the new construction going on in the fertilizer industry, market power is not expected to be operated this way (Heffer and Prud'homme, 2011, 2012).

[14] We have already noted the Chinese floods in 2010 (also Pakistan) and there were adverse weather conditions in 2007 in Texas. Moreover, in the United States, this was the period of rapid expansion of maize for biofuel. So, these factors contributed to fertilizer demand shifts.

during adverse rainfall years in the production of processed foods.

In 2013, the new sorghum cultivar, Grinkan, with the other technology components discussed, has been moving across the Koutiala region and has also been introduced into the cotton zones of Burkina Faso and the higher rainfall region of Niger, Gaya. In Mali, in 2013, the Development Bank (BNDA) provided loans for fertilizer purchases for 8,000 ha in the Koutiala region for the new technology-marketing sorghum activities modeled here. Besides bank loans the farmers' associations have been able to get contracts with large merchants bypassing local and nearby town merchants and thereby enabling the farmers' associations to obtain larger shares of the marketing margins (Jean-Francois Guay, former director of the IICEM program in Mali, personal communication). In Burkina Faso, the Ministry of Agriculture promoted the introduction of 1,000 ha of Grinkan combined with fertilizer in 2013 providing small quantities of both for farmers in the cotton zone. In Garasso, Mali where the new sorghum cultivar, Grinkan, was introduced in 2008 as part of the technology-marketing package discussed here, surrounding villages called the cultivar "the cotton of Garasso."

Appendix A: Price determination and states of nature

Econometric techniques using time series data were employed to estimate the postharvest conditional price distributions. The yearly time series data covers the period 1998 to 2008. OLS regressions on grain prices to reflect their conditionality nature with time series price observations across 10 years are estimated.

Harvest prices are influenced by yield outcomes. The first set of regressions estimated indicates the dependence between yearly harvest prices and yields for the grains sorghum, maize, and millet (Eqs. (A.1)–(A.3). The relationships between own harvest prices and yields from 1998 to 2007 are

$$P_{st1} = \underset{(58.88)}{336.94} - \underset{(0.09)}{0.24}\, y_{st1} \qquad \text{Rsquare} = 0.40 \tag{A.1}$$

$$P_{mt2} = \underset{(132.57)}{305.62} - \underset{(0.14)}{0.20}_{ymt2} \qquad \text{Rsquare} = 0.12 \tag{A.2}$$

$$P_{Mt2} = \underset{(52.04)}{178.20} - \underset{(0.03)}{0.05}\, y_{Mt2} \qquad \text{Rsquare} = 0.22 \tag{A.3}$$

(Standard errors are reported in parentheses),
where, *Pst*1, *Pmt*1, *PMt*1 are, respectively, harvest prices for sorghum, millet, and maize in year *t*; and *yst*1, *ymt*1, and *yMt*1 represent the yields for sorghum, millet, and maize in year *t*.

In the second set of regressions, prices for sorghum, millet, and maize in the recovery season have been regressed against own harvest prices. Three sets of OLS regressions have been performed (Eqs. (A.4)–(A.6). 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% to the grain prices for the month of October and November and a weight of 60% for the month of December. Prices in the recovery period are represented by the average

Table A1
Harvest time prices (F CFA/kg) for grains

Years	Millet	Sorghum	Maize
1998	153	119	96
1999	94	80	64
2000	82	65	67
2001	128	114	98
2002	170	157	130
2003	83	56	49
2004	109	90	84
2005	115	96	87
2006	82	69	62
2007	87	82	83
2008	104	80	86

Table A2
Recovery time prices (F CFA/kg) for grains

Years	Millet	Sorghum	Maize
1998	131	135	113
1999	69	73	64
2000	140	117	114
2001	185	185	157
2002	175	157	130
2003	74	65	60
2004	164	158	149
2005	126	108	96
2006	85	73	71
2007	103	90	101
2008	123	109	113

Table A3
Hungry time prices (F CFA/kg) for grains

Years	Millet	Sorghum	Maize
1998	119	124	100
1999	70	65	63
2000	167	153	120
2001	204	202	167
2002	153	115	79
2003	80	72	73
2004	210	196	148
2005	128	103	77
2006	93	93	88
2007	137	120	136
2008	156	138	120

price of April and May. Farmers' objective is to sell their stock of grains during those months as prices often experience sizable increase. But farmers need income for input purchases before the next planting season. The following regressions were estimated between harvest prices and prices in the recovery period:

$$P_{stp} = 24.38 + 0.99 P_{stp-1} \quad \text{Rsquare} = 0.46 \tag{A.4}$$
$$\qquad (32.85) \quad (0.34)$$

$$P_{mtp} = 28.53 + 0.88 P_{mtp-1} \quad \text{Rsquare} = 0.36 \tag{A.5}$$
$$\qquad (40.40) \quad (0.35)$$

$$P_{Mtp} = 21.34 + 1.03 P_{Mtp-1} \quad \text{Rsquare} = 0.43 \tag{A.6}$$
$$\qquad (31.42) \quad (0.37)$$

where standard errors are reported in parentheses; *Pstp*, *Pmtp*, and *PMtp* are, respectively, the prices of sorghum, millet, and maize in year t and marketing period p (April, May); and *Pstp*−1, *Pmtp*−1, and *PMtp*−1 stand for the prices of sorghum, millet, and maize in year t in the lag marketing period $P_{\text{p}-1}$ (harvest).

In the third set of regressions (Eqs. (A.7)–(A.9), 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. The strong relationships between prices in the lean season and prices in the two preceding periods are reported below:

$$P_{stp} = 48.50 + 1.52 P_{stp-1} - 1.08 P_{stp-2} \quad \text{Rsquare} = 0.94 \tag{A.7}$$
$$\qquad (13.11) \quad (0.14) \qquad (0.19)$$

$$P_{mtp} = 42.24 + 1.43 P_{mtp-1} - 0.77 P_{mtp-2} \quad \text{Rsquare} = 0.96 \tag{A.8}$$
$$\qquad (14.26) \quad (0.12) \qquad (0.16)$$

$$P_{Mtp} = 50.78 + 1.29 P_{Mtp-1} - 0.99 P_{Mtp-2} \quad \text{Rsquare} = 0.81 \tag{A.9}$$
$$\qquad (22.04) \quad (0.24) \qquad (0.35)$$

where standard errors are reported in parentheses; *Pstp*, *Pmtp*, and *PMtp* are, respectively, the prices of sorghum, millet, and maize in year t and marketing period p (August, September); *Pstp*−1, *Pmtp*−1, and *PMtp*−1 stand for the prices of sorghum, millet, and maize in year t in the first lag marketing period *Pp*−1 (April, May); and *Pstp*−2, *Pmtp*−2, and *PMtp*−2 stand for the prices of sorghum, millet, and maize in year t in the second lag marketing period *Pp*−2 (harvest).

The values of the error terms in the grain price regression equations for each marketing period were used to construct the probability distribution of prices in each marketing period. Since observations for prices are only available for 10 years, 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 17 × 10 × 10 × 10. 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.

Appendix B

Real aggregate yield observations and monthly prices were only available for a 10-year 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:

$$y_{mt} = -1062.51 + 31.59 X_t - 0.12 X_t^2 \quad \text{Rsquare} = 0.75 \tag{B.1}$$
$$\qquad (463.89) \quad (7.69) \quad (0.03)$$

$$y_{st} = -1809.86 + 45.01 X_t - 0.18 X_t^2 \quad \text{Rsquare} = 0.77 \tag{B.2}$$
$$\qquad (528.50) \quad (8.76) \quad (0.04)$$

$$y_{Mt} = -3505.93 + 80.52 X_t - 0.30 X_t^2 \quad \text{Rsquare} = 0.58 \tag{B.3}$$
$$\qquad (1976.90) \quad (32.76) \quad (0.13)$$

where y_{mt}, y_{st}, and y_{Mt} are, respectively, yield for millet, sorghum, and maize in year t; and X_t and X_t^2 are, respectively, the rainfall observation and the quadratic term for rainfall in year t.

For cotton, in addition to rainfall, exogenous cotton prices set by the para-statal company at the beginning of the agricultural season are expected to impact the allocation of land to cotton

Table B1
Yield in kg/ha, rainfall in mm, and real cotton price (CFA/kg) from 1980 to 2009

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

Note: Observed yields are from 1998 to 2007. Predicted yields are from 1980 to 1997 and from 2008 to 2009 following the above 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.

and influence significantly cotton yield. Therefore, cotton prices from 1980 to 2009 were added in the cotton yield regression equation as shown below:

$$\begin{aligned} y_{ct} &= -3050.75 + 53.59X_t - 0.21X_t^2 + 3.15P_{ct} \\ &\quad (1166.40)\ \ (18.47)\quad\ (0.07)\quad\ (0.89)\ \ \text{Rsquare} = 0.63 \end{aligned} \tag{B.4}$$

where y_{ct} is the cotton yield in year t, P_{ct} is the cotton price in year t.

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.

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