MSU International Development Working Paper

Sorghum Productivity in Mali: Past, Present, and Future

by

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MSU International Development Working Paper 138
July 2015

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MSU Agricultural Economics Web Site: http://www.aec.msu.edu
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ISSN 0731-3483

Published by the Department of Agricultural, Food, and Resource Economics and the Department of Economics, Michigan State University, East Lansing, Michigan 48824-1039, U.S.A.

ACKNOWLEDGMENTS

Funding for this research was provided by the Bill and Melinda Gates Foundation through a grant to Michigan State University under the project titled Guiding Investments in Sustainable Agriculture in Africa (GISAIA).

The authors wish to thank Melinda Smale, who provided invaluable assistance in the design of the paper and editing of early drafts, and Patricia Johannes for her editing and formatting assistance.

The authors bear fully responsibility for the contents and an interpretation of the findings reported here.

EXECUTIVE SUMMARY

Objectives

Mali has a long history of focusing agricultural research and policies on the cereal sector, as cereals are the major staples providing food security. Despite the overall success of Malian cereal research and market reforms, recent production and productivity trends for traditional coarse grains (millet and sorghum) have grown at a much slower pace than rice and maize. This literature review describes how Mali is currently performing in terms of sorghum productivity, how the sector got to where it is today, and issues that need to be addressed to further its development. Sorghum is the focus of the review because of its adaptability to a variety of climates and the role it plays in providing food security to semi-subsistent rural households.

Key Findings

Supply, demand, and prices. Mali's primary source of sorghum supply is national production, 80-90% of which is consumed by semi-subsistence farmers and never passes through a market. National data contrasting average annual production from 1964-1999 with that from 2000-2013 show a doubling of absolute levels between the two periods, with current production concentrated in four regions: Sikasso (30% of national production), Koulikoro (29%), Kayes (19%), and Ségou (17%). These shares do not reflect, however, the role that sorghum plays within the agricultural economy of each region. In Kayes, for example, sorghum represents 63% of total cereal production while it is only 39% of cereal produced in Sikasso, where maize is also an important crop. Despite aggregate growth in sorghum production, average yields and sorghum's share of national production are declining and sorghum markets remain poorly developed.

Demand trends are more complex to describe. Estimates of per capita sorghum consumption using data from Mali's *Observatoire du Marche Agricole* (OMA) show increased consumption since 1993, while a comparison of expenditure data for 1989 and 2006 shows that households are spending a declining share of their cereal budget on sorghum and millet with an increasing share going to maize and rice. Although Malian consumers are reducing sorghum expenditure shares, there is good evidence of growing regional demand for Malian sorghum, particularly from structurally food insecure neighbors, and for use of sorghum in the manufacture of animal feed.

For the most part, commercial market transactions determine consumer and producer prices of all cereals. Given national food security concerns, however, the government does play a role in stabilizing prices through market transactions implemented by the *Office des Produits Agricoles du Mali* (OPAM). OPAM interventions often have limited impact due to inadequate or late funding. A comparison of price trends for millet, maize, and sorghum shows that the three cereals track each other closely in both urban and rural markets, with millet usually the most and maize the least expensive. Lower prices for maize can make it more attractive than sorghum for animal feed.

Government policies. Key policy drivers of sorghum production and marketing trends include:

- Cereal market reforms during the 1980s that liberalized markets, but failed to elicit the magnitude of supply response that was anticipated (most farmers continue to consider sorghum and millet as subsistence rather than cash crops).

- National agricultural strategies and investments that have tended to favor the maize and rice sectors, such as:
  - Cotton programs (which supported much of the initial research on maize variety improvement, extension services, and credit systems) promoted rapid growth in maize production and adoption of improved maize technologies while no comparable programs were available for sorghum and millet.
  - Investments in irrigation for rice production have favored zones where irrigation is possible, with no comparable investments in dry-land agriculture.
  - Agriculture subsidies re-instated since 2008 have directly benefited rice, cotton, and maize producers; they were belatedly offered to sorghum producers but with few positive impacts because sorghum farmers rarely use chemical fertilizer and improved seeds and do not generally have access to input credit.
- Regional trade policies (e.g., cereal export bans, rice import tax holidays) that tend to keep prices low favor consumers over producers and traders
- Inadequate investment in transport infrastructure and poor control of unofficial *road taxes* that raise the costs of moving cereals from surplus to deficit zones.
- Recent uncertainty about the future of the Malian cotton sector raises questions about access to inputs and input credit, leading some farmers to opt for low-input sorghum production in lieu of maize and improved sorghum varieties that require more fertilizer.

Of note is the relatively small effect of the 1994 currency devaluation, which should have favored growth in demand for domestic cereals but had limited impact as urban consumers cut back on other expenditures to maintain rice consumption. In addition, many of the structural adjustment policies during the 1990s, which reduced input subsidies and were much decried by rice, cotton, and maize farmers, had little impact on sorghum producers who received little subsidy or extension support from government before the reforms.

At present, the overall stated economic policies of Mali are market-oriented, yet poor urban consumers represent a serious political concern and that concern results in policies such as cereal export bans or price controls that negatively affect cereal farmers and traders. In fairness, however, one must also take into account Mali's overall policy framework and how well it has done in terms of ensuring national food security. A comparative study of Mali, Gambia, and Côte d'Ivoire following the 2008 food price spike crisis found that Mali had realized important food security benefits from its policies that lessened the negative impacts compared to neighboring countries.

Agricultural research contributions to sorghum productivity. Mali has an impressive record for the production of new and well performing sorghum varieties. Accomplishments through the 1990s included 13 improvements in local varieties and four key groups of new varieties. The research also brought increased attention to photoperiod-sensitive varieties. Since 2000 there has been more participatory breeding and multi-locational testing of varieties at an earlier phase of development, with efforts to link farmer and community organizations more closely to research and to supply seed in a more decentralized way. The success of these changes is illustrated by the 38 sorghum varieties currently disseminated in Mali, of which 13 have been released since 2008 and 11 are hybrids. An ICRISAT study in 2010 ranked Mali second among five West African countries in terms of variety releases from 1970 – 1990 and first for the 1990 to 2010 period.

Research on agronomic practices has paralleled research on sorghum breeding. Topics covered include seeding densities, fertilization using organic and inorganic fertilizers as complements and/or substitutes, crop rotations to increase yields and improve soil fertility, and land preparation methods to increase soil moisture retention. Recent agronomic research showing particular promise for coarse grain producers includes fertilizer micro-dosing, intercropping, and soil and water conservation plowing techniques. Some of this research is being done as part of an initiative to address climate change. In general, the literature review found few economic analyses of these various recommendations.

Dissemination strategies and adoption. Research successes have not been rapidly transformed into the levels of farmer adoption that researchers and extension services would like to see. The major strategy for dissemination of new varieties has been through various projects promoting farmer managed seed production enterprises and from programs to expand industrial demand for varieties of sorghum with good processing qualities. Financial sustainability has been an issue for the former (costs exceed revenues due to low sales volumes) while farmers' inability to provide a reliable supply discourages investment in the processing sector. On the agronomic practices side, weak extension services outside the cotton and rice sectors is a constraint. NGOs (e.g., Sasakawa Global 2000) with access to international funding seem to be more active in disseminating research results for coarse grains than government extension services.

There is very limited information about what farmers are actually doing in terms of sorghum varieties planted, fertilizer used and other management practices. Several studies of variety adoption have been conducted, but different data collection and estimation methods produce different results—estimates of the percent of sorghum area planted to improved varieties range from 13% (nationally representative surveys) to 18% (estimate based on seed production data) to 30% (geographically targeted studies). Not only is better adoption data needed, but to increase its usefulness there needs to be disaggregation by types of farmers and locations. For example, do men vs. women or young vs. old adopt different varieties, use different agronomic practices, or obtain different yields? Are there geographic *hotspots* for adoption of improved sorghum varieties? What are the crops and varieties on which farmers are using fertilizers?

Despite the weaknesses, a synthesis of all the varietal adoption studies does suggest increased adoption over time, with more rapid growth in recent years, and a need to better integrate market channels for the sale of improved and traditional varieties. On the other hand, declining trends in sorghum yields for the recent past lead one to question the relatively high adoption rates reported in some studies and/or question the extent to which recommended agronomic practices are being used with the improved seed.

Issues Needing Attention

Although most reviews of Mali's sorghum variety improvement research have been favorable, questions remain as to whether appropriate strategies are in place to promote adoption of these latest varieties and adequate resources are in place to monitor adoption.

Extension Services. Formal extension services to promote sorghum are extremely weak, so alternative mechanisms for introducing the improved varieties to farmers who are outside the main Institut d'Economie Rurale (IER) and International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) test areas will be needed. Can NGOs serve this purpose? What about agro-dealers?

Monitoring Adoption. Adoption studies reviewed were few and variable in results, providing no basis to recommend any particular dissemination strategy. Consequently, testing and monitoring the results of a variety of approaches to introduce different types of farmers to different types of sorghum technologies seems an appropriate next step given the recent breakthroughs in variety releases and evidence of adoption in ICRISAT test villages. There also needs to be more attention to monitoring complementary agronomic practices. Research results suggest significant yield and income gains are possible with micro-dosing of fertilizers and a variety of soil and water conservation practices applied to improved varieties. Five areas where systematic data collection is needed if researchers are to have more impact include:

- Levels and speed of technology adoption
- Feedback from farmers on reasons for adoption
- Farmers' perceptions of constraints to adoption
- Farm characteristics that are favorable to adoption (e.g., age, gender, location)
- Yield increases due to technology adoption
- Effect of adoption on income (or other indicators of well-being)

Targeting. To what extent should new varieties be targeted to farmers producing only for the market or also to farmers producing primarily for home consumption? Are some of the improved varieties better for marketing and others better for home consumption? Other aspects of the targeting issue include how strategies might differ by a farmer's access to inputs, average level of rainfall, access to markets and roads, or access to land. Sorghum varieties often perform best in very site-specific environments, adding another challenge.

Seed supply. There is more optimism now than in the past about the development of seed production cooperatives and commercial firms, with ICRISAT reporting increased quantities of seed being produced, the Alliance for a Green Revolution in Africa (AGRA) supporting a number of agro-dealers who are selling sorghum seed, and evidence of increased monetization of seed exchanges. These programs need to be monitored and sustainability of the seed enterprises evaluated.

Demand. The potential for growth in sorghum demand needs to be better understood. Most coarse grain analysts focus on the growing industrial demand for maize and pay little attention to sorghum.

Reconciling research results and national statistics. The most worrisome part of the picture is that there is little evidence in aggregate statistics to show that farmers are increasing either sorghum area or yields. These statistics do not seem consistent with what one would expect with estimates that roughly 30% of the sorghum area has been planted to improved varieties since the mid-1990s. Why the differences?

Lessons from maize and rice? The contrast between the large positive impact of government programs and policies on rice and maize production and their less perceptible impact on sorghum production illustrates the need to foster synergies to elicit strong agricultural productivity growth in the sorghum sector. Attention must be directed simultaneously at technology development, strengthening and reform of institutions governing production and marketing, and macro-economic policy reform if sorghum is to realize its full potential to contribute to Mali's food security and poverty reduction goals. The marketing reforms in the *Office du Niger* were effective largely because farmers in the zone had the technical capacity to respond quickly by intensifying production and the government was investing in both irrigation and roads. Similarly, extension services and input supply provided by the *Compagnie Malienne pour le Développement des Textiles* (CMDT) in the cotton zone encouraged the surge in maize production. Now that Mali has significant breakthroughs in sorghum variety improvements, and some signs of farmer interest in the new varieties, it is time to get the rest of the system up and running.

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AFRIPRO	A program focused on studying protein content of African foods
AGRA	Alliance for a Green Revolution in Africa
AHMED	A Malian Non-governmental organization
ASTI	Agricultural Science and Technology Indicators
CAADP	Comprehensive Africa Agriculture Development Programme
CGIAR	Consultative Group for International Agricultural Research
CILSS	*Comité permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel (Permanent Interstates Committee for Drought Control in the Sahel)*
CIRAD	*Centre de Coopération Internationale en Recherche Agronomique pour le Développement*, replaced by *l'Institut de Recherche pour le Développement (IRD).*
CMDT	*Compagnie Malienne pour le Développement des Textiles*
CORAF/WECARD	*Conseil Ouest et Centre Africain pour la Recherche et le Développement Agricoles*
CPS/SDR	*Ministère du Développement Rural, Cellule de Planification et de Statistique Rural*
DIIVA	Diffusion and Impact of Improved Varieties in Africa, a Bill and Melinda Gates Foundation Project
DRA	*Direction Régional d'Agriculture*
EAC	*Enquête Agricole de Conjoncture*
ECOWAS	Economic Community of West African States
FAO	Food and Agriculture Organization of the United Nations
FCFA	West African Franc (Malian currency)
fte	full-time equivalent
GDP	Gross Domestic Product
GIE	*Groupement d'Intérêt Economique*
GOM	Government of Mali
IBPGR	International Board for Plant Genetic Resources, replaced by par Bioversity International
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IER	*Institut d'Economie Rurale*
IER/ECOFIL	*Institut d'Economie Rurale/Etudes des Filières*
IFPRI	International Food Policy Research Institute
IICEM	USAID's Integrated Initiatives for Economic Growth in Mali
INTSORMIL	A USAID-funded millet/sorghum project conducted in collaboration with IER
IPR/IFRA	Rural Polytechnic Institute for Training and Applied Research
IRAT	*Institut de Recherches Agricole Tropical*
NARS	National Agricultural Research Centers
OHVN	*Office de la Haute Vallée du Niger*
OMA	*Observatoire du Marche Agricole*

ON	*Office du Niger*
OPAM	*Office des Produits Agricoles du Mali*
ORSTOM	*Office de la Recherche Scientifique et Technique d'Outre-Mer*
PAPAM	*Programme d'Accroissement de la Productivité Agricole au Mali*
PASAOP	*Programme d'Appui aux Services Agricoles et aux Organisations Paysannes*
PNIP	*Plan National d'Investissement Prioritaire dans le Secteur Agricole*
PNRA	World Bank funded National Agricultural Research Project
ReSAKSS	Regional Strategic Analysis and Knowledge Support System
ROCARS	West and Central Africa Sorghum Research Network
SANREM	Sustainable Agriculture and Natural Resource Management Collaborative Research Support Program
SG2000	Sasakawa Global 2000
T&V	Training and Visit approach to extension
UEMOA	French acronym for WAEMU
USAID	United States Agency for International Development
WAEMU	West African Economic and Monetary Union

1. INTRODUCTION

Sustainable growth in farm productivity for staple crops is a principal policy goal for most African governments. Rapid population growth and urbanization, combined with rising food prices, have increased both the urgency and the potential for achieving this goal. The urgency is underscored by forecasts calling for worldwide increases in maize and sorghum production of 111% and 107% to meet 2050 food demand (Kruse 2010).

In response to the devastating droughts and hunger of the 1970s-1980s, Mali's agricultural research system increased efforts to improve yields of sorghum and millet, supported initially by the United Nations Development Program, United States Agency for International Development (USAID), and since 1975, by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Before 1960, sorghum research had been conducted by French colonial research institutes such as the *Institut de Recherche en Agronomie Tropicale* (IRAT). The Malian *Institut d'Economie Rurale* (IER), founded in 1960, continued these activities in collaboration with the French and others.

Since the 1980s, Mali has sought to stimulate greater food production by small-scale farmers through policy reforms and agricultural support programs. Despite the overall success of Malian market reforms, production of traditional coarse grains (millet and sorghum)—which are grown under rainfed conditions, with fewer improved technologies, and often in places where the basic transportation infrastructure is weak—have grown at a much slower rate than rice and maize (Dembélé and Staatz 2002). The contrast between the large positive impact of policy reforms on Mali's rice and maize production and its less perceptible impact on millet/sorghum production illustrates the need to elicit stronger agricultural productivity growth for millet and sorghum.

Drawing on an extensive review of published and unpublished documents, this paper describes Mali's sorghum sector, how the sector got to where it is today, and what can be done to further its development. Sorghum is the focus because of its adaptability to a variety of climates and the role it plays in providing food security to semi-subsistent rural households, which produce primarily for home consumption. Since 1964, land cultivated with sorghum has averaged 30% of Mali's cereal area and accounted for 29% of cereal production. Despite sorghum's continued importance, a recent research and policy focus on maize and rice seems to be relegating sorghum to the status of an orphan crop, with its shares of cereal area and of production declining. Declining shares raise questions about what is behind the changes and what they mean for consumers, farmers, processors, agricultural researchers, policy analysts, and the Government of Mali (GOM), which has a broad mandate to reduce poverty and ensure food security for all its citizens—including those who live in agro-ecological zones where maize and rice production are not possible.

The paper starts with a description of Mali's sorghum production zones and a discussion of changing patterns in sorghum supply, demand, and prices. Next, it looks at government policies and investments that have influenced the sector. This is followed by a review of sorghum research and technology dissemination strategies, with a focus on the current state of the art (most promising technologies and agronomic practices available). A discussion of adoption and farm-level impacts of adoption brings the literature review to a close. In a final section, the key lessons from past experience are summarized and used to make recommendations about future development of the sorghum sector in Mali.

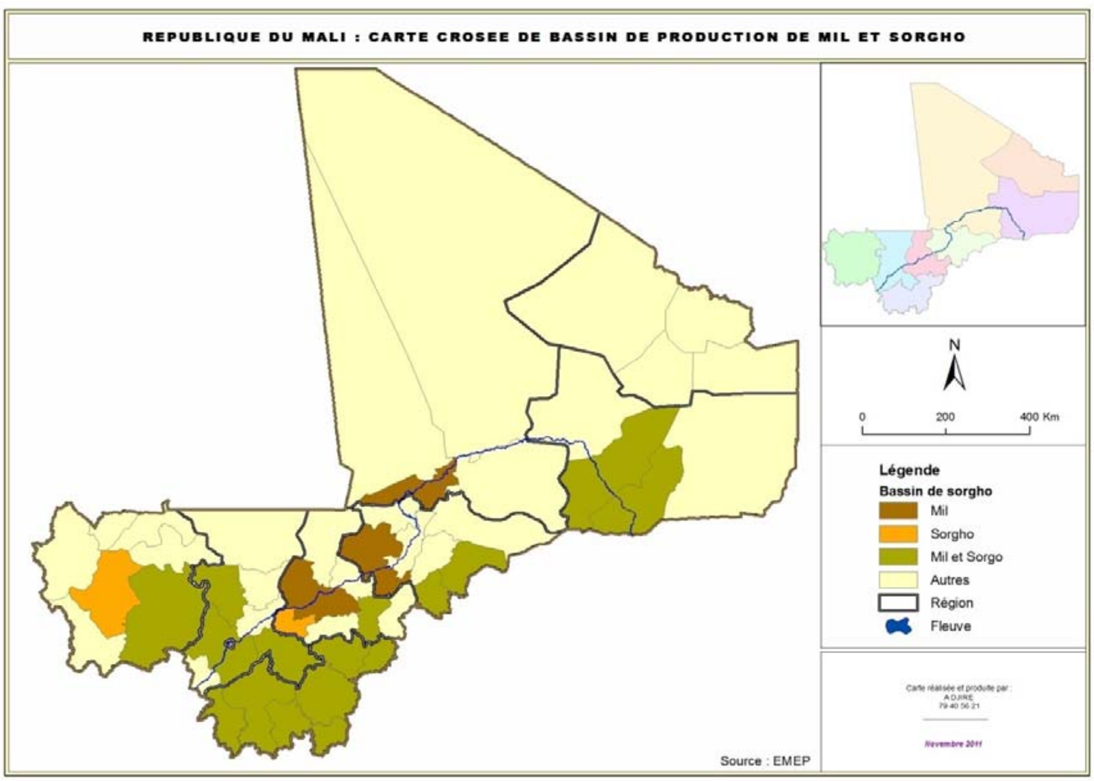
2. SORGHUM SUPPLY, DEMAND, AND PRICES

2.1. Supply

Farmers' personal preferences for home consumed cereals and their perceptions of market demand and prices shape their decisions about what crops they grow, how much of each they produce, what production technologies they use, and how much they sell. In turn, these decisions shape cereal supply. Mali's sorghum supply comes primarily from domestic production, which is spread across a wide band of agricultural land in the southern half of the country where millet is also commonly grown (Figure 1). Appendix 1 provides descriptive information on the characteristics of the agro-ecological zones where sorghum is grown in Mali. In general, farms in the northern half of these cereal production basins are characterized by millet/sorghum cropping systems which are adapted to the lower rainfall of 600 to 800 mm/year. Rainfall increases toward the south (800-1,000 mm/year), where maize and sorghum are rotated with cotton.

In addition to being grown in several agro-ecological systems, sorghum is also integrated in several production systems (Table 1). The more important include (1) the cotton system, (2) the peanut system (into which cotton is currently being introduced), (3) the millet/sorghum system, and (4) the recessional (*décrue* in French) system. The cash crops of cotton and peanuts serve as the engine for the first two cropping systems, which are accompanied by

Figure 1. Millet and Sorghum Production Basins



Source: PROMISAM 2011.

Table 1. Primary Malian Production Systems that Include Sorghum

Systems	Regions	*Cercle*s	Extension	Engine crops
Cotton system	Sikasso	Sikasso, Koutiala, Kadiolo, Bougouni, Kolondiéba, Yanfolila	CMDT et OHVN	Coton
	Koulikoro	Koulikoro, Kangaba		
Peanut system (becoming Cotton system)	Kayes	Bafoulabé, Kita, Kéniéba	CMDT/ DRA	Arachide/cotton
	Koulikoro	Kolokani		
System based on millet and sorghum	Kayes	Kayes, Nioro	DRA	-
	Koulikoro	Koulikoro, Nara Kolokani, Kangaba		
	Sikasso	Yorosso		
	Ségou	Ségou, San,Tominian		
	Mopti	Bandiagara, Koro, Bankas, Douentza		
Recessional (décrue) system	Kayes	Yélimané	DRA	-
	Tombouctou	Tombouctou, Diré, Goundam, Rharous, Nianfunké		
	Gao	Gao, Ansongo		

Source: Authors' classifications drawing on a variety of earlier work by the Institut d'Economie Rurale, Division Planification et Evaluation.

more intensive and sustained extension services from the *Compagnie Malienne pour le Développement des Textiles* (CMDT) and the *Office de la Haute Vallée du Niger* (OHVN) than the millet/sorghum and recessional systems, which rely entirely on the *Direction Régionale de l'Agriculture* (DRA) for extension support.

Ninety percent or more of national production comes from four administrative regions: Sikasso, Koulikoro, Kayes, and Ségou. Sikasso is the biggest supplier averaging 30% of production from 1984-2013,[1] followed by Koulikoro (29%), Kayes (19%) and Ségou (17%). From a regional perspective, however, sorghum is relatively more important in Kayes (63% of the region's cereal production) and in Koulikoro (47%), somewhat less important in Sikasso (39%) where maize dominates and only 19% of production in the Ségou Region, where millet is the primary coarse grain. These two perspectives— national and regional— both need to be considered when making decisions about sorghum productivity research, poverty reduction, and targeting of programs to disseminate research results.

Appendices 2-4 provide *cercle*-level information on cereal production in Mali. This includes two maps showing the geographic intensity of sorghum and millet production by *cercle* and a table reporting cereal production by crop and *cercle* from 1990 to 2005. Data collection since 2005 no longer supports *cercle*-level analyses. In terms of sorghum production by *cercle*, Koutiala traditionally produced the most, followed by Kolokani and Kita. For millet, Segou

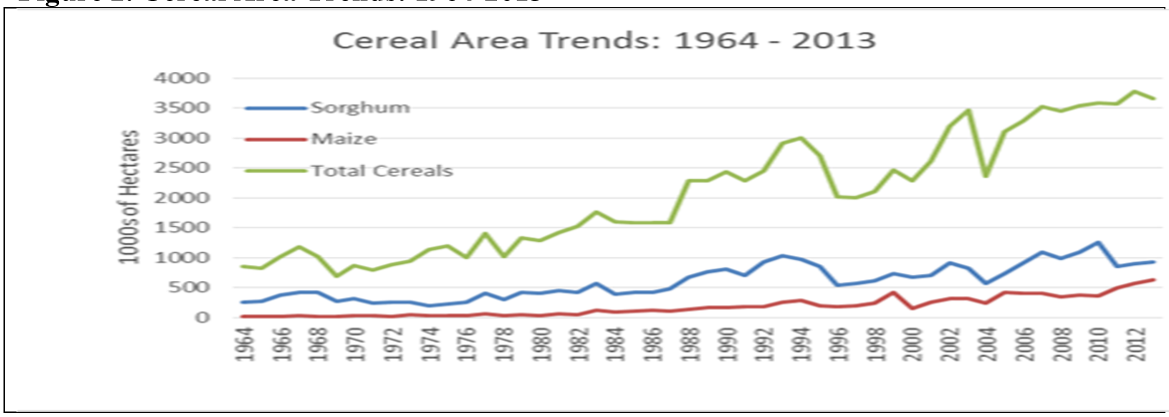
[1] Full data on sorghum production by region was not available prior to 1970.

produced the most followed by Koro, Bankass, and Baraouéli. Maize, which competes with sorghum, is concentrated in Kadiolo, followed by Yanfolila and Sikasso.

Mali's average annual domestic sorghum supply since 2000 is double that from 1964-1999 (871,309 tons vs 432,668 tons)—primarily a result of area expansion. Area planted showed little change from 1964 to the mid-1980s, then it began to increase and to show more inter-annual variability (Figure 2), while yields remained flat (Figure 3). The 2004 Agricultural Census reported that area planted to sorghum was 31% in Koulikoro and 22% in Sikasso regions.

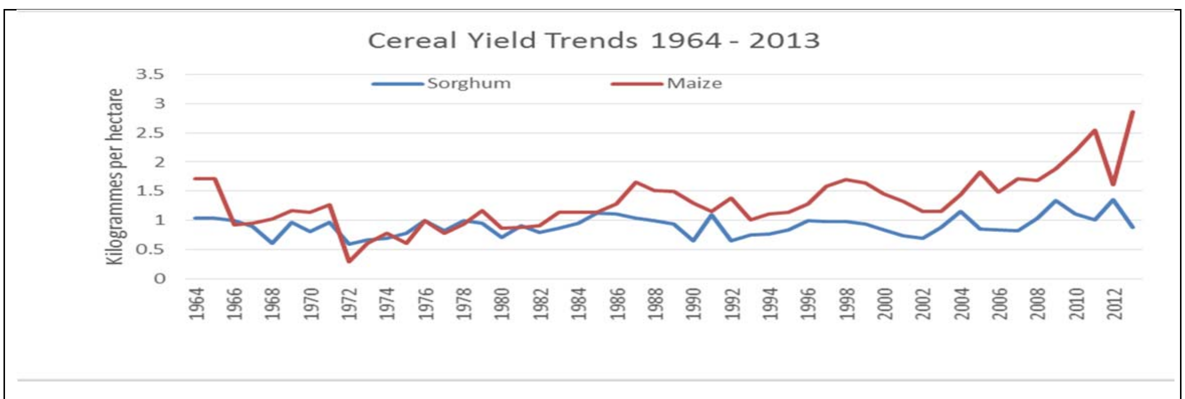
Figure 3 shows that maize and sorghum traded places frequently in terms of yields with both trend lines relatively flat until the mid-1980s when maize yields began an upward climb leaving sorghum yields behind.[2] It was in the mid-1980s that Mali's cotton company began to promote maize production.

Figure 2. Cereal Area Trends: 1964-2013



Source: Calculated by authors using official CPS database.

Figure 3. Cereal Yield Trends: 1964-2013



Source: Calculated by authors using official CPS database.

[2] The linear trend line for maize yields from 1985 - 2013 is y= 0.0318 + 1.0636 with an $R^2$of 0.41; that for sorghum was y = 0.0041 + 0.8829 with an R^2 of only 0.037.

Despite growth in aggregate production, sorghum's share of national cereal production declined from an average of 31% (1984/5-1999/2000) to 22% (2000/01-2013/14); its share of coarse grain production (maize, millet, and sorghum) declined from 37% to 31%. Production also exhibits geographic shifts, with Koulikoro and Sikasso increasing their contribution to national supply while contributions from Kayes and Ségou declined. In all four regions sorghum has declined as a share of regional cereal production since 2000.[3]

Since millet and sorghum have long been considered subsistence rather than commercial crops, farmers require a major change in mindset to adopt technologies needing a marketable surplus to cover costs. We know of no nationally representative estimates of coarse grain sales for Mali as a share of total production. Data from a survey conducted in three production zones in Mali showed that in Koutiala, a major cereal production zone in the CMDT, 2006/07 sales represented 9% of millet production and 14% of sorghum production. Results for the 2008/09 season for millet and sorghum combined were only 7%. Other zones in the study (Tominian and Macina in the Ségou Region) sold less than 5% of production each year. Based on this survey data and secondary sources, Staatz et al. (2011) estimated that not more than 20% of national millet/sorghum production is likely to be marketed in a year of good production, with the average across years probably being 10% or less.

2.2. Demand

Looking at sorghum from the demand side, we find that Malian consumer preferences are shifting away from coarse grains. Following the 1994 devaluation, urban consumption studies indicated that consumers preferred to maintain rice consumption and cut corners elsewhere rather than switching to less expensive coarse grains (Reardon et al. 1998; Singaré et al. 1999). A more recent expenditure analysis reinforces this finding using two nationally representative budget/consumption surveys (ReSAKSS or Regional Strategic Analysis and Knowledge Support System 2010). Although the overall share of cereals in total food expenditure barely changed, increasing from 39% in 1989 to 40% in 2006, the relatively stable overall shares are *not* mirrored by the individual cereals—rice shares increased while coarse grain shares generally declined (Table 2).

At the same time that expenditure shares for sorghum appear to be declining, data on cereal consumption from Mali's *Observatoire du Marche Agricole* (OMA) suggests that absolute quantities of sorghum and other coarse grains have been increasing in terms of per capita consumption since 1993 (Figures 4 and 5).

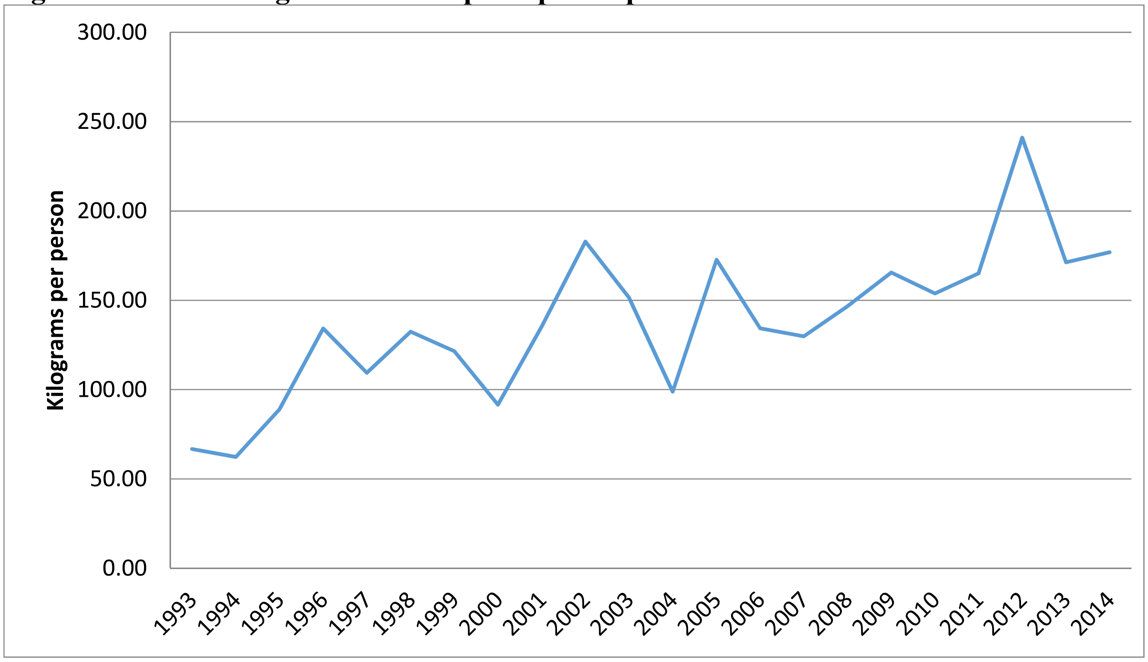
Table 2. Food Expenditure Shares for Cereals

Product	1989			2006		
	Urban	Rural	National	Urban	Rural	National
Sorghum	5.4	11.4	9.3	3.2	7.6	5.7
Rice	16.0	9.2	11.5	20.3	17.3	18.6
Millet	6.4	17.8	13.9	6.7	15.6	11.8
Maize	1.6	4.2	3.3	2.6	4.9	3.9
Wheat	1.9	0.5	1.0	0.3	0.2	0.2
All cereals	31.3	43.1	39.0	33.1	45.6	40.2

Source: Kelly et al. 2012, using data reported in ReSAKSS 2010.

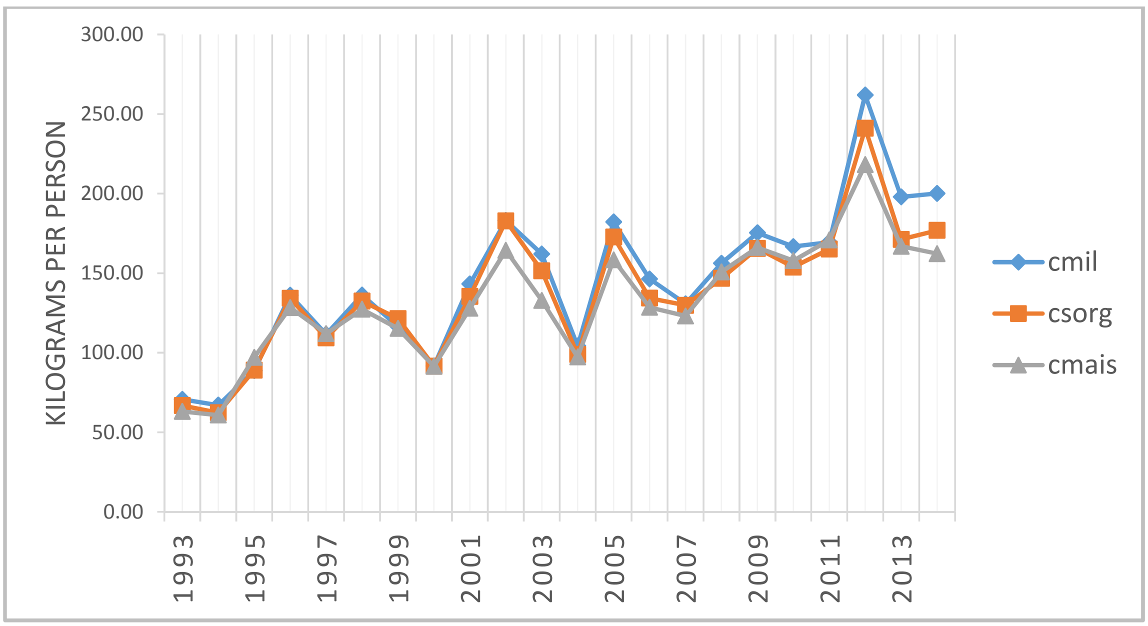
[3] Authors' caclulations using official CPS production, area and yield data.

Figure 4. Annual Sorghum Consumption per Capita: 1993-2014



Source: Graphs created by the authors from the OMA 2015 database with the assistance of A. Ahamadou.

Figure 5. Annual Coarse Grain Consumption per Capita: 1993-2014



Source: Graphs created by the authors from the OMA 2015 database with the assistance of A. Ahamadou.

Despite the growing preferences for rice, there is optimism concerning industrial demand for coarse grains, primarily for animal feed but also as a partial replacement for wheat flour in pastries, breads, and crackers. Maize, however, is the preferred coarse grain for animal feed, preferred by egg producers for its contribution to yellow yokes and by all meat producers for its lower price relative to sorghum (Diallo 2011 citing Sanders and Ouendeba 2010; Sanders and Ouendeba 2012).[4]

There is also some optimism concerning Mali's ability to respond to regional export markets in structurally food insecure neighbors (e.g., Senegal and Mauritania), and markets with intermittent shortages (e.g., Niger and Nigeria). Although statistics on cereal exports for Mali are considered very rough approximations due to porous borders, Table 3 summarizes statistics for 2008-20013 collected and analyzed by USAID-funded trade projects. The data suggest relatively small export quantities in general but with sharp inter-annual fluctuations (e.g., the differences between 2011 and 2012)

Analyses that are now dated (e.g., Barry 1994; Stryker et al. 1987) found Mali to have a competitive advantage for cereals in neighboring markets. More recent analyses (e.g., Stryker and Coulibaly 2011; Mas Aparisi, Diallo, and Balié 2013) are more guarded, largely because of the poor quality of data and uncertainty about whether coarse grains should be treated as tradable or non-tradable products. Despite different views about competitiveness, there is general agreement that a number of policy and institutional issues need to be addressed if Mali is to thrive in regional markets. First and foremost, farmers must start viewing these crops as having commercial rather than simply subsistence uses and organize themselves to market cereals in a coherent, predictable manner rather than in millions of small lots when some quick cash is needed (Smale et al. 2014). Additional improvements include grades and standards to meet industrial needs, more reliable credit and input supply—including seeds of improved varieties preferred by processors, open borders allowing supplies to move from surplus to deficit countries, and regional market information systems (Kelly, Dembélé, and Staatz 2008)

Table 3. Malian Cereal Export Data from USAID-Funded Projects

	2008	2009	2010	2011	2012	2013
	(Metric tons)					
Total Cereal Exports	720	3,600	2,987	8,487	428	883
Maize	720	3,600	2,340	4,614	331	-
Millet	-	-	447	2127	44.2	883
Sorghum	-	-	200	1746	53	-
Total Cereal Exports by Destination						
Mauritania	720	3,600	1,391	2,972	193	576
Senegal	-	-	1,356	3,945	225	307
Côte d'Ivoire	-	-	240	1,570	10	-
Sorghum Exports by Destination	0	0	200	1,746	53	0
Mauritania	-	-	5	1,177	-	-
Senegal	-	-	195	569	53	-
Côte d'Ivoire	-	-	-	-	-	-

Source: Niang, Plunket, and Guiro 2013. Note: For 2008-2012 the data are from USAID Expanded Agribusiness and Trade Promotion project and were supplied by the Permanent Interstates Committee for Drought Control in the Sahel (CILSS) for analysis by USAID's Integrated Initiatives for Economic Growth in Mali (IICEM) project. Data for 2013 cover only April and May and were supplied by CILSS.

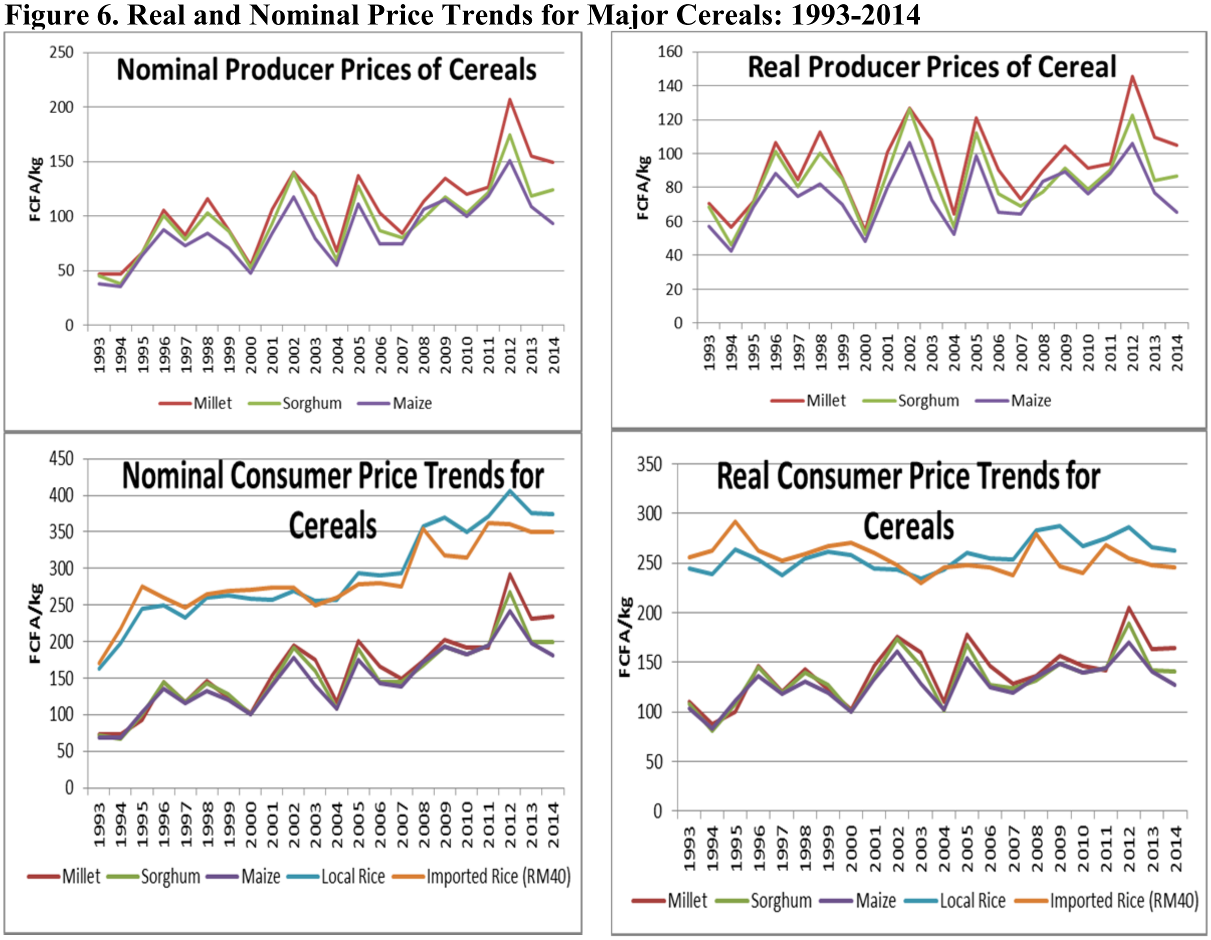
[4]Low-tannin sorghum varieties have 95 to 97% the feed efficiency for poultry as maize; therefore, to be competitive with maize as a feed ingredient, the prices of these varieties need to be 95 to 97% the price of maize.

Other constraints relate to reliable production as markets do not do well without a steady supply. A final point about demand that is also relevant to supply is the lack of data or modeling of elasticities—a data gap that constrains analyses of potential responses by consumers and producers to policy and technology changes.

2.3. Prices

Since the mid-1980s, cereal prices in Mali have been determined primarily by market forces and OMA has collected price data in both consumer and producer markets. Nominal and real price trends are shown in Figure 6 for a variety of consumer and producer cereal prices. The graphs hold no surprises. Sorghum prices are closely aligned to millet and maize prices, with millet generally the highest of the three and maize the lowest. Consumer prices of all the coarse grains are considerably lower than local and imported rice prices. During the 1993-2014 period all prices but those of imported rice have been increasing on average, though there has been a recent decline that was particularly sharp for coarse grains between 2012 and 2013.

Figure 6. Real and Nominal Price Trends for Major Cereals: 1993-2014

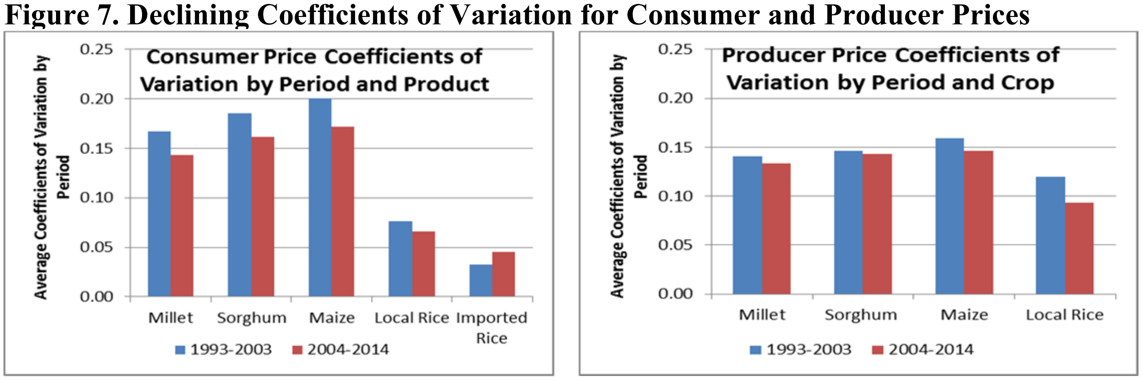


Source: Authors' analysis of OMA price data using the International Labor Organization's general price index as a deflator. Consumer prices are for the Niarela market in Bamako and producer prices for the Koutiala market in the Sikasso Region. Other rural sorghum markets (e.g., Koulikoro, Bla, San) had price patterns for sorghum similar to Koutiala.

A linear time trend fitted to the nominal consumer prices resulted in R squares in the 0.7 to 0.8 range (i.e., much of the variability could be explained by the time trend) and coefficients suggesting average annual increases in the 6 to 9 FCFA/year range. Results for the real consumer prices were less robust: R squares from 0.14 to 0.42 and coefficients ranging from less than 1 (imported rice) to almost 3 (millet). A linear trend for nominal producer prices explained 45-55% of the variability with coefficients for annual change in the 3 to 4 FCFA range. For the real producer prices the linear trends had R squares less than 0.20 and coefficients ranging from 0.9 to 1.6. In short, prices exhibit a lot of inter-annual variability while the long-term trends are characterized by relatively small average annual increases in real prices.

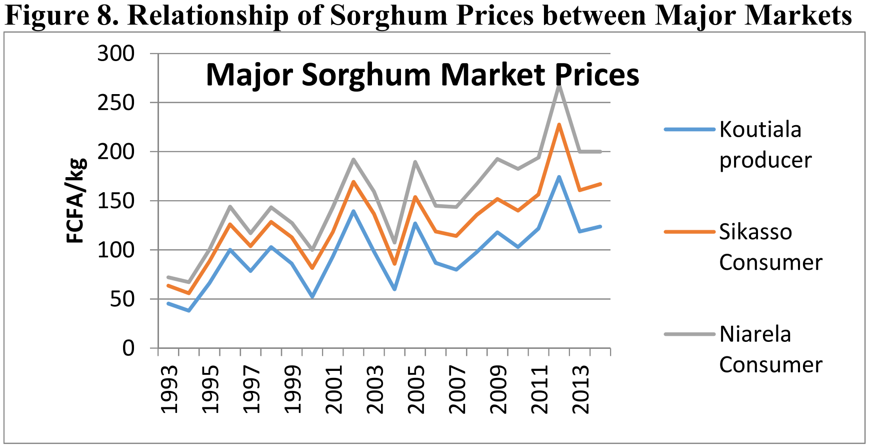
Figure 7 illustrates that despite the continued fluctuation in prices, coefficients of variation for the mean prices have declined from 1993-2003 to 2004-2014. They are slightly higher for consumer prices than for producer prices and higher for coarse grains than for rice. They have also declined more for consumer prices than producer prices between the two periods. The only increase in variability was for imported rice, likely due to the price spikes in 2007 and 2008. Figure 8 illustrates the typical relationship among sorghum prices at a producer market (Koutiala), an intermediate consumer market (Sikasso Centre), and a Bamako market (Niarela).

Figure 7. Declining Coefficients of Variation for Consumer and Producer Prices



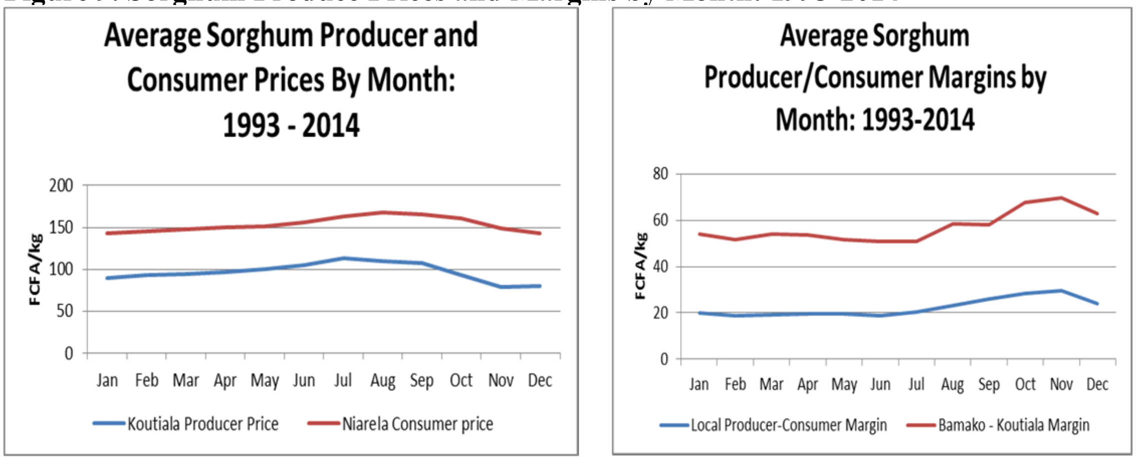
Source: Authors' calculations from OMA price data for Bamako and Koutiala.

Figure 8. Relationship of Sorghum Prices between Major Markets



Source: Authors' calculations from OMA price data for Bamako, Sikasso, and Koutiala.

Figure 9. Sorghum Produce Prices and Margins by Month: 1993-2014



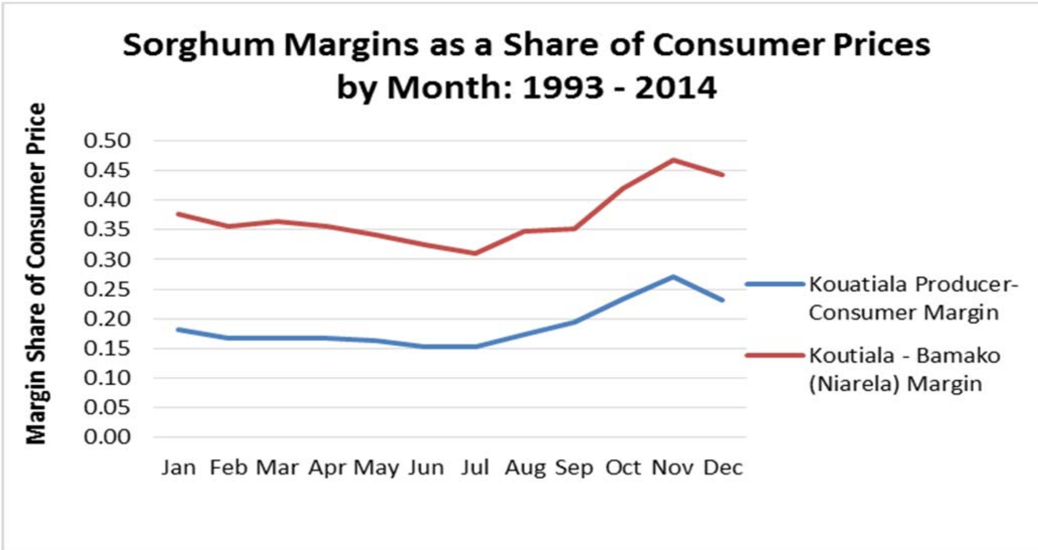
Source: Authors' calculations using OMA price data for Koutiala and Niarela (Bamako) markets.

Starting in the mid-2000s, average margins (distances between the trend lines) appear to have increased from roughly 35% of the final consumer price between 1993 and 2004 to 39% for the 2004 through 2014 period. Figure 9 illustrates that there is seasonality in both prices and margins.

Producer prices begin rising slowly in December/January and continue rising to July, when they level off and then decline with the September/October harvest. Bamako consumer prices have a similar pattern but with a less noticeable decline after harvest. Local Koutiala margins were in the 20 to 25 FCFA/kg range from 1993-2014 and tended to be relatively stable from January through July, when they began rising throughout the harvest season before declining again in December. The Bamako-Koutiala margins averaged 55 to 65 FCFA/kg during the 1993-2014 period. While they have more inter-month movement than the local Koutiala margins, they too rise most significantly from August through November and decline again in December. Figure 10 illustrates that the increases in margins from August through November are not simply due to the increase in prices but also include an increase in the share of the consumer price contributing to the margin. For Koutiala, the margin's share from January through July is 16% versus 22% for August through December; comparable shares for the Niarela-Koutiala margins are 35% and 42%.

Over all, sorghum prices seem to have followed the same trends as those of other coarse grains and do not show any particular propensity to provide incentives for farmers to shift from other crops to sorghum. This suggests that growth in sorghum production will most likely need to be stimulated by increased demand and/or improvements in productivity that do not also raise costs of production. Another way of stimulating coarse grain production would be to reduce marketing margins, leaving a larger share of the consumer price with farmers, but this would not be likely to favor sorghum over other coarse grains. We also need to better understand the causes of the recent price declines after so many years of continuous increases to be sure that they represent a temporary blip rather than a new trend.

Figure 10. Margins as a Share of Consumer Prices by Month: 1993-2014



Source: Authors' calculations using OMA price data for Koutiala and Niarela (Bamako) markets.

3. WHAT IS BEHIND SORGHUM AREA, PRODUCTION, AND YIELD TRENDS?

The evolution of Malian agricultural strategies provides some insight into the drivers of sorghum production and productivity, yet the more direct influences tend to be the policies, programs, and investments actually put in place by the GOM to support the strategies. We first describe how sorghum fits into stated strategies and then highlight key policies, programs, and investments that either supported or thwarted the development of the sector.

3.1. Agricultural Strategies

Colonial agricultural policies focused on production and export of cash crops, particularly cotton; farmer support programs and research efforts paid little attention to coarse grains such as sorghum. After independence, support to domestic cereal production increased with the creation of cereal research units at the IER and further intensified with the advent of recurrent droughts in the 1970s. At the same time, a heavy government hand controlled cereal markets and did little to encourage cereal market development. During the late 1980s and 1990s cereal market reforms took center stage, based on the assumption that they would encourage farmers to produce marketable surpluses that would improve national food security. This was followed by more than a decade of structural adjustment reforms, including currency devaluation in 1994, reductions in agricultural subsidies, and donor-backed efforts to privatize agricultural support activities traditionally carried out by government development offices such as the *Compagnie Malienne pour le Développement des Textiles* (CMDT) and the *Office du Niger* (ON) irrigated rice system.

In 2001, the Council of Ministers identified cereals—with millet, rice, sorghum, maize, and wheat specifically mentioned—as one of 13 agricultural growth sectors in their investment strategy (Integrated Framework Team 2004). A 2009 statement by the Ministry of Agriculture made clear the government's intent to pursue much greater expansion of the maize sector than of the millet and sorghum sectors. The plan involved continued increases in the absolute amount of millet/sorghum production but a relatively sharp drop in its share of total cereal production (from its then current level of 50-60% to 33% by 2012/13). Increases in maize production were expected to compensate, by moving from 15% of production to 39%. The officially announced (*Ministère de l'Agriculture* 2009) approach to sorghum was:

> …to limit area cultivated and improve yields in the principal production zones (southern region, areas of recessional or dune agriculture where appropriate varieties have been developed) by the use of agroforestry practices, soil and water conservation techniques, crop rotations, and organic fertilizers. Varieties to encourage will be those that produce white flour, which is better adapted to industrial processing. (Translated from the original French).

By September, 2010, the draft *Plan National d'Investissement Prioritaire dans le Secteur Agricole (*PNIP-SA) had expanded this approach to include intensification of sorghum production on 30% of its currently planted acreage, with the aim of raising average yields from roughly 1 ton/ha in 2010 to 2 tons/ha on this area by 2015 (*République du Mali* 2010).

The challenges faced by those designing Mali's recent cereal sector development strategies are described in a report examining the financial and economic costs and benefits of the PNIP-SA (Stryker and Coulibaly 2011). While the PNIP-SA called for substantial increases in the use of fertilizers and other improved technologies to expand millet and sorghum production, the assessment was quite conservative in its views on the feasibility of expanding these two crops:

> …while it is relatively safe to invest in intensification of maize production, especially in relatively well watered areas, it is premature to move forward rapidly with intensification of millet and sorghum production until the improved technologies for these crops have been thoroughly tested under scaled-up conditions (Stryker and Coulibaly 2011, page 30).

The report noted that there were technology packages currently being tested and disseminated by IER, INTSORMIL, IICEM, AMEDD, DRA, and Sasakawa Global 2000, that showed promise of substantial increases in yields with the use of improved seed, moderate dosages of fertilizer, and improved agronomic practices; but the authors felt that there was not yet solid evidence that these technologies would be adopted by farmers at the level required to make the millet/sorghum parts of the PNIP-SA feasible to implement.

3.2. Policies, Programs, and Investments

3.2.1. Cereal Market Reforms

The GOM took control of cereal markets in 1964 with the creation of the *Office des Produits Agricoles du Mali* (OPAM), which was granted a legal monopoly on the grain trade. Through OPAM, the government fixed official producer and consumer prices for cereals, with three objectives: increasing rural incomes, providing cheap cereals to urban areas, and extracting a surplus from agriculture to finance other government investments. Because OPAM was forced to absorb the implicit consumer and producer subsidies resulting from price policies, its cumulative budget deficit reached FCFA 20 billion (US$80 million) by 1976/77, equivalent to three times its annual grain sales (Humphreys 1986). Several analyses in the 1980s drew attention to the need to take markets and economics into account when designing policies to promote coarse grain production (e.g., Staatz, Dioné, and Dembélé 1986; Staatz 1989).

Reforms began in 1981 with the *Programme de Restructuration des Marches Céréaliers* and lasted more than ten years transforming the cereal market to one managed by the give and take of independent cereal traders and consumers. Reforms involved liberalizing producer and consumer prices, liberalizing grain trade, and improving OPAM's operating efficiency. (Egg 1999; Dembélé and Staatz 2002; Dioné 2000). The government role in cereal markets at present is primarily one of providing some financial support to an agricultural price information service (OMA) and maintaining a national cereal stock of roughly 30 to 40 thousand tons. Through its authority to make cereal purchases and sales in support of the security stock, the GOM can play a role in stabilizing cereal prices. Millet and sorghum benefited from reforms but the supply response was weaker than for rice and maize, due to limited availability of improved technologies and poor infrastructure in millet/sorghum zones (Staatz et al. 2011; Kelly et al. 2012; Soulé and Gansari 2010).

3.2.2. Macro-economic Policy: Devaluation and Structural Adjustment

In 1994, the West African Economic and Monetary Union (WAEMU) implemented a 50% devaluation of the CFA franc. The devaluation made Malian exports such as cotton more competitive in international markets but also raised the price of food imports (e.g., Asian broken rice) relative to domestic cereals. In theory, these price changes should have increased demand for domestic cereals and given Malian farmers an incentive to increase production. The down side of the devaluation for farmers was more expensive imported fertilizer, although this had little impact on sorghum producers who seldom used it. Devaluation did, however, affect maize producers, whose profits declined due to their heavier reliance on fertilizers.

In the two decades of Structural Adjustment reforms following the devaluation, reductions in subsidies and support programs had relatively little impact on the majority of sorghum farmers because they were not previously benefiting from such programs. Government imposed changes on producer organizations were also targeted to rice and cotton producers so affected only the sorghum farmers in these zones.

Since the liberalization of input supply in the 1990s, the private sector has developed into a number of small, under-capitalized businesses with relatively poor knowledge of international fertilizer markets and weak negotiating skills that result in high priced imports and late deliveries (Tyner et al. 2002; Kelly 2000; Kelly et al. 2005). A few producer organizations in both the rice and the cotton zones have also engaged in fertilizer imports (Bingen 2003; Konen 2008). Pressure to change input procurement procedures in the CMDT zone has also negatively affected coarse grain producers (see Box 1).

Seed supply became an issue in Mali in the late 1990s and early 2000s when donors and researchers began to blame low adoption of improved varieties on the poor performance of the National Seed Service (Christiansen and Cook 2003). This led to a variety of projects to create seed production and marketing enterprises, yet achieving financial sustainability for them has been difficult. The small quantities of sorghum seed required per hectare and the possibility of recycling non-hybrid seed for 3 to 4 years makes developing a profitable sorghum seed supply business challenging. A further challenge is posed by cultural attitudes toward seed:

> …consistent with other research on the topic (Sperling et al. 2006; Smale et al. 2008; Coulibaly et al. 2008), Siart (2008) found that customary norms discouraged commercial purchase or monetized exchanges of seed among farmers. Customarily, seed diffusion depends very much on personal relations, seeds are not ascribed a monetary value, and farmers do not sell seeds. (Smale et al. 2014).

More recently, fertilizer and seed markets have been affected by the 2008 introduction of a government input subsidy program.

Box 1. CMDT Input Procurement Reforms

Historically, the CMDT obtained inputs for all crops via international tenders and sold them to farmers on credit, using the cotton harvest as the collateral for the credit. As part of the cotton sector restructuring process, CMDT transferred responsibility for what they considered non-critical inputs used for cereals to farmers in 2000 while it continued to manage cotton inputs. In 2008, preparation for the privatization of the CMDT and general dissatisfaction with the systems put in place for *non-critical* inputs led to the creation of a *Groupement d'Intérêt Economique* (GIE) to procure all cotton and non-cotton inputs. The GIE is managed by representatives of OHVN, CMDT, the cotton producer organization *Union Nationale des Sociétés Coopératives de Producteurs de Coton du Mali* and the *Groupement des Syndicats Cotonniers et Vivriers du Mali*. We have no recent information on the performance of the system, but believe it has been procuring inputs (pesticides, and fertilizers) since 2008 through international tenders. It is not yet clear how input procurement will be handled in the cotton zone after the CMDT is privatized, although the GIE is expected to play a role. Source: Adapted from Staatz et al. 2011.

3.2.3. Input Subsidies

Government subsidies to agriculture have been direct and indirect and most often administered through the development offices such as the CMDT, OHVN, ON, and Opération Riz Ségou. Indirect subsidies have come primarily in the form of input credit guarantees that were covered by the government when farmers defaulted on their loans—only a small share of these credit guarantees were ever available for sorghum production. Seed production and distribution by the National Seed Service has also been supported by the government with seed prices often below costs of production to encourage adoption.

The subsidy program of relevance today began as the *Initiative Riz*. The 2008 commodity price spike was a wake-up call to politicians, who rapidly put in place a program to stimulate cereal production—first targeted to assist rice producers during the 2008/09 season and then expanding to stimulate coarse grain production in 2009/10.[5] The program, which is still in place, provides farmers growing targeted crops subsidized seeds and fertilizers. An early evaluation reported that:

> The program has been criticized for having used inappropriate procedures for selecting suppliers, for late deliveries of fertilizers in 2008/09, poor controls on the movement and distribution of stocks to farmers, excessive costs, delayed payments to several suppliers in 2009/10 that increased interest payments, and failure to develop adequate monitoring systems to measure program impacts. Nevertheless … the overall program contributed to the following positive outcomes:
>
> - 20% increase (over 2007/08) in fertilizer utilization in the Ségou Region;
> - 48% increase in rice area in the Mopti region and 16% increase in the Ségou Region;
> - An unquantifiable increase in producer incomes due to the combined effects of relatively high rice prices, increased production, and lower input costs (Staatz et al. 2011 citing *Bureau de Vérificateur Général du Mali* (2009) and interviews with fertilizer suppliers).

A subsequent analysis reported that the subsidy had permitted an increase in fertilizer consumption and contributed to an increase in production and productivity, particularly for maize, cotton, millet, and sorghum. In addition, the agricultural contribution to the Gross Domestic Product (GDP) increased from 430 to an average of 642 billion FCFA from 2007/08 to 2010/11 with rice's contribution more than doubling (from 104 to 221 billion FCFA) and maize's contribution increasing from 62 to 104 billion FCFA. The contributions of millet and sorghum both declined (see Box 2 for a direct quote from Diakité et al. 2013b).

Although the authors attribute these changes to the subsidy, the data and analytical methods used do not always appear robust enough to have isolated the effects of the subsidy from other factors affecting cereal areas and yields. Given the small amounts of fertilizer currently used on sorghum, the fertilizer subsidy program is not likely to be having much of an impact on production decisions; however, if fertilizer responsive sorghum varieties are adopted by farmers the situation may change. The declining contribution of sorghum as a share of GDP is not unexpected given government strategies mentioned earlier.

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[5] Coarse grains became eligible for the subsidy during the 2009/10 season but problems with the availability of subsidized fertilizers in 2009 meant that the program was not effectively implemented until 2010/11.

Box 2. Input Subsidy Impacts

… la subvention des intrants agricoles a permis de relever le niveau de consommation des engrais au Mali et ceci a eu comme conséquence une augmentation de la production et de la productivité des principales cultures. Cette hausse de la consommation moyenne d'engrais est remarquable surtout sur le maïs, le coton et le mil/sorgho… (Diakité et al. 2013b, page 62)

De la campagne 2007/2008 à 2010/2011, la contribution de l'ensemble des filières étudiées à la formation du PIB du secteur agricole aux coûts des facteurs … est passée en moyenne de 430 à 642 milliards de FCFA par an. La contribution de la branche rizicole est passée de 104 milliards à 221 milliards de FCFA. Le maïs suit avec une contribution qui est passée de 62 à 104 milliards de FCFA. … des parts de contribution pour les mils ont diminué de 36% à 26% et de 18% à 15% pour le sorgho (Diakité et al. 2013b, page 14).

Discussions of the subsidy focus on farm and production impacts, ignoring the effect on input suppliers. Government services now play a significant role in determining demand and organizing delivery—private suppliers tend to wait each year to see what the government does before getting involved.

3.2.4. Cotton Sector Policies

An important share of Mali's sorghum (as well as maize, the main competition to sorghum in the higher rainfall zones) is produced in the cotton zone. Cereal and cotton production decisions are intertwined through a complex system of crop rotation considerations to maintain soil fertility and input credit, input supply, and output marketing policies managed by the CMDT and the OHVN (see Dioné 1989; Tschirley, Poulton, and Labaste 2009; Theriault 2011; Laris, Foltz, and Voorhees 2015). Although there is an ongoing debate about whether cotton farmers get better cereal yields or produce more cereal than their non-cotton producing neighbors (Dalton 1996; Pieri 1989; van der Pol 1992), there is general agreement that cotton production gives farmers better access to extension services, to agricultural equipment, and to inputs that benefit both cotton and cereals (Boughton and de Frahan 1994; Staatz et al. 2011; Diallo 2011; Sanogo, Keita, and Sanogo 2009). The cotton sector was found to be the main driver of Sahelian input demand of all kinds during the 1990s—particularly fertilizer, but also improved seeds (Kelly 2000).

Changes in cotton sector policies affect cereal production decisions. When farmers decrease cotton area they tend to decrease maize area (correlation coefficient of +0.52) while sorghum area increases (correlation coefficient of -0.14). Sissoko et al. (2013) found this relationship particularly visible from 2000 on (Appendix 5). The explanation for the positive correlation with maize is that participation in the cotton program provides access to fertilizers that can be used for maize; sorghum, on the other hand, can be grown adequately without fertilizer. Maize also benefits from residual cotton fertilizers when it follows cotton in the crop rotation whereas sorghum does not (Sissoko et al. 2013). Greater availability of high performing maize varieties—compared to sorghum—also influences farmers' decisions about which cereals to produce. In the 1980s, CMDT actively supported the introduction of improved maize varieties and production practices as part of the recommended cereal/cotton rotations; this decision is often credited with starting what is known as Mali's maize revolution.

Maize is becoming a substitute or supplementary cash crop, and green maize is also harvested by smallholder farm families as needed to bridge to hungry season.[6] Some believe that maize is now able to develop independently from cotton thanks to the process of intensification, the use of improved varieties, and the increasing demand from newer consumption markets (e.g., poultry feed) that has induced more production (Diallo 2011). Sorghum's role in all this seems to be as the *fallback* crop when cotton sector problems balloon and inputs are not available for maize or farmers are simply too poor or risk-averse to pay for expensive cereal inputs.

3.2.5. Trade Policies

Since 2000, the introduction of common tariffs throughout the West African Economic and Monetary Union (WAEMU; UEMOA is the French acronym) and efforts to extend them to the entire Economic Community of West African States (ECOWAS) has increased regional trade, particularly for cereals and livestock. Proponents of regional integration of West African cereal markets have argued that because regional production levels are less volatile than country-specific levels, regional integration should reduce price volatility at the national level through spatial and temporal arbitrage (Badiane 1998, for example). Mali has developed what is generally viewed as a market-oriented agricultural development policy open to regional and world markets; however, fears persist that Malian consumers could be hurt by cereals flowing to countries with greater purchasing power. Following price spikes in 2008, the GOM used subtle tactics[7] to unofficially stem the flow of cereals from Mali to its neighbors because an official trade ban would contravene ECOWAS agreements. These unofficial barriers do not stop trade but they significantly increase transactions costs and opportunities for corruption at border crossing. (Kelly et al. 2012; Kelly, Dembélé, and Staatz 2008). Overall, the regional markets remain largely in the hands of the private sector, but much can be done in terms of infrastructure and reduction of transactions costs to make them more efficient.

3.2.6. Research Policies and Support

Although some sorghum research was conducted during the colonial period and continued after independence, it wasn't until after 1975 that IER and ICRISAT set up a collaborative cereals and oils research program. This was followed by the 1988 creation of an ICRISAT sorghum improvement program and the 1990 creation of an IER sorghum program. The two Malian institutions of most importance to sorghum research are the IER (230 full-time equivalent (fte) researchers in 2011) and the Rural Polytechnic Institute for Training and Applied Research (IPR/IFRA) under the University of Bamako (48 fte researchers) (Stads, Maiga, and Magne Domgho 2014). These national institutes broaden their capacity for both research and dissemination through collaboration with international research centers in the CGIAR (Consultative Group for International Agricultural Research) system and other organizations such as AGRA, CORAF, ROCARS, SANREM, INTSORMIL, SG2000, and AHMED. IER has particularly close relationships with AGRA, ROCARS, and INTSORMIL.

[6] A crucial agronomic feature of maize in West Africa is that it can mature before the end of the rains; while sorghum and pearl millet need to flower just before normal end of rains (after wild grasses mature), so that bird damage can be minimized (Eva Weltzien, personal communication).

[7] For example, the forms required for declaring exports were not available to traders.

Since 2000, the ASTI program (Agricultural Science and Technology Indicators) has been monitoring agricultural research capacity in roughly 20 African countries (Stads and Kouriba 2004; Beintema and Stads 2011; Stads, Maiga, and Magne Domgho 2014). [8] Since the indicators program began, Mali's agricultural research capacity and performance has been relatively strong compared to other countries in the region, but performance indicators tend to rise and fall. ASTI's overall assessment in 2014 is that Mali's agricultural research sector faces three major challenges: over-reliance on donor funding, a low agricultural research intensity ratio, and an aging researcher community with an inadequate supply of new researchers waiting in the wings (Stads, Maiga, and Magne Domgho 2014).

In terms of researcher capacity, Mali had 233 fte researchers in 2000; the number rose to 319 in 2008 and dropped to 307 by 2011. Of this 2011 total, IER had 230 fte researchers and the IPR/IFRA had 48. The share of researchers with PhD degrees increased considerably from 17% in 1990 to 33% in 2011; similar changes for MS degrees have taken place (from 13% to 52%). By 2008, Mali ranked fourth in the ASTI indicators for share of researchers with either an MS or a Ph.D. Another indicator of researcher capacity—fte researchers per 100,000 farmers—was 9.8 in 2000, rose to 10.95 in 2008, but fell back to 9.8 in 2011. In 2008, only eight SSA countries did better than Mali on this indicator.

The overall agricultural research capacity described above does not necessarily reflect what is available for sorghum research. Although coarse grains represent Mali's major crop category in terms of area and production, rice—thought to have the greatest developmental potential—was the primary crop focus at IER in 2001, occupying 37% of fte researchers. Sorghum was second in importance with 13% of IER and 50% of IPR/IFRA researchers focusing on it. We have not found comparable data for more recent years, but a 2011 count of researchers working on five specific crops in Mali (ground nuts, cowpeas, maize, millet, and sorghum) reports 23 fte researchers working in ten subject matter areas (breeding, pathology, molecular biology, entomology/nematology, agronomy, seed production, soil science, food science, social science, culture) (Diffusion and Impact of Improved Varieties in Africa or DIIVA data base 2011). Of the 23 fte researchers, 34% are working on some aspect of sorghum; of these 40% have a PhD, 35% an MS, and 24% a BS. The DIIVA database does not include researchers at IPR/IFRA and differs in other key ways from the ASTI approach to data collection (Walker et al. 2014).

In terms of finances, Mali's total agricultural research spending (33.6 million 2005 PPP dollars for 2011[9]) is higher than neighboring Senegal (24.8), Burkina Faso (25.4), and Mauritania (8.9). Mali's spending as a share of agricultural GDP, however, has declined from 1% (the recommended level) in 2000 to 0.61% in 2011; Senegal and Mauritania had higher intensities in 2011 (0.83% and 0.80%), Burkina was lower (0.42%), and the Sub-Saharan African average was 0.51%. Mali's agricultural research is more dependent on donor funding (63%) than her neighbors; nine other West African countries all had lower dependence in 2011, ranging from 7% (Côte d'Ivoire) to 60% (Burkina Faso) and only five countries in Sub-Saharan Africa had greater donor dependence. Between 1994 and 2001, just one-third of the total budget came from the national government, another third through the World Bank funded National Agricultural Research Project (PNRA), and the remainder from bilateral and foundation donors. PNRA was immediately followed by another World Bank project—the

[8]ASTI comprises a network of national, regional, and international agricultural R&D agencies and is managed by the International Service for National Agricultural Research division of the International Food Policy Research Institute.

[9] Equivalent to 51.1 million in 2011 PPP dollars.

Box 3. Overview of Mali's Agricultural Extension Structure and History

Malian extension services (ES) include (1) governmental and parastatal organizations providing the bulk of the services, (2) non-governmental organizations and projects providing temporary or occasional ES, and (3) ES offered through private-sector entities.

Governmental ES can be further divided between the services of principal Ministries that coordinate and provide services in their specific technical domains (crops, livestock, etc.), and the various *Offices du développement rural*, which dominate extension for a particular zone or crop (e.g., CMDT).

Services offered through non-governmental organizations are usually funded by international donors and often work through the governmental programs, providing additional training and operational support to governmental field staff in targeted geographic areas. Malian NGOs providing extension and advisory services to farmers organizations during the past 10-20 years include *Groupe de Formation, Consultation et Étude*, the *Institut Africain de Gestion et de Formation*, and *Association Conseil pour le Développement*.

In the *Offices* and the *CMDT*, extension traditionally followed the *filière intégrée* approach to subsector management where extension was built into the overall development programs for the targeted crops. Despite a substantial body of literature praising many aspects of the vertically integrated systems that provided inputs and credit and reliable output markets to farmers as well as some of the better research-extension linkages observed in Africa (Tschirley, Poulton, and Labaste 2009), Mali was forced to abandon the approach during structural adjustment and to reduce the scope of services offered to cotton farmers.

There was significant downsizing of direct government extension programs under structural adjustment. This led to the World Bank supported Training and Visit (T&V) approach introduced in the early 1990s. T&V was accompanied by efforts to transfer greater responsibilities to rural producers through development of Village Associations, assisted by an unpaid cadre of village *animateurs*, with the target of establishing *Villages Auto-Encadrés*. Funding of Mali's T&V experience ended in 1999, at which time support for national agricultural extension was transferred to the World Bank projects, PASAOP I & II. PASAOP was a period of experimentation with a user-fee approach and added support in creating *Centres de Gestion*, and contractually engaged private ES providers. Those involved in implementing the user-fee approach saw it as a failure, with essentially no buy-in by producers—ultimately interpreted as being due to a lack of market integration.

The major World Bank agricultural program in 2010, *Programme d'Accroissement de la Productivité Agricole au Mali* (PAPAM), reportedly did not include any direct financing for extension, nor was core funding for the provision of ES from other donors identified.

Source: Adapted from Staatz et al. 2011 citing Simpson and Dembélé 2010.

Agricultural Services and Producer Organizations Program (PASAOP), which tried to better integrate research and extension (see Box 3). As donor contributions increased during this period, government contributions declined in real terms, from $10 million in 1994 to $6 million in 2001, raising concerns about sustainability. The 2012 *coup d'état* also had a negative impact on research funding as major donors (World Bank, European Union, and the African Development Bank) suspended their support to IER.

3.2.7. Extension Policies and Support

The need for better integration of research and extension activities was raised by the World Bank projects described above, in a 2005 USAID-funded technology assessment report for Mali (Kelly et al. 2005), and in an assessment of ICRISAT's sorghum and millet research program conducted in the 1990s (Yapi et al. no date and 2000). Box 3 describes the three main components of Mali's extension system. Like the agricultural research services, extension has been heavily dependent on donor funding but less successful than the research services in maintaining adequate levels. With the bulk of extension funding going to the *Offices* and CMDT, sorghum tended to be neglected, except for farmers who fell under the umbrella of the CMDT. As noted in Box 3, the World Bank, which has recently been the primary source of extension funding outside the Offices and CMDT, did not include such support in its 2010 *Programme d'Accroissement de la Productivité Agricole au Mali*, leaving the extension services without an operations budget.

A comparative study of extension services in Mali and Guinea (Stoop 2002; Stoop 2003) concluded that much remained to be done to improve productivity among resource poor farmers—a group of interest to this study given its focus on sorghum. The report argued that Malian extension put too much focus on intensification and efficiency, while farmers were most concerned with risk. The report called for "…fundamental changes in the approaches to research and extension in support of the resource-poor." To accomplish this,

> …research should be able to develop and to propose to farmers a wide range of technological options (representing different levels and types of intensification as concerning internal and external input use) to better satisfy the diverse needs of different categories of farmers (Stoop 2003).

A scenario with farmers using the low-input varieties as a safety-net approach for their subsistence production and the high-input varieties on land they devote to cash crops could be the future outcome.

3.3. Overall Impact of Policies, Programs, and Investments on the Sorghum Sector

While the overall stated economic policies of Mali are market-oriented, poor urban consumers represent a serious political concern for the GOM and that concern often determines policies that affect cereal markets. This was observed in 2008 with a number of *market unfriendly* efforts by the GOM to put a lid on rising cereal prices (Kelly, Dembélé, and Staatz 2008; Staatz et al. 2008).

Some have also attributed the slow pace of growth for sorghum (and millet) to skewed investments that favor rice and maize. An early example of this is the CMDT program that successfully introduced cotton farmers to maize production with credit, input supply, and extension programs that led to rapid adoption of improved maize varieties (developed with funding support from CMDT), increased maize area, and increased yields (Boughton and de Frahan 1994). The down side of the rapid expansion due to CMDT efforts came when structural adjustment reforms reduced the CMDT's ability to continue several of their maize support programs (Boughton, Staatz, and Shaffer 1994). The initial impetus given to the sector seems to have carried it through the hard times, however, as maize production continues to expand at a rapid pace (Diallo 2011).

More recently, Mas Aparisi, Diallo, and Balié (2013) estimated nominal protection coefficients for sorghum and millet concluding that farmers were penalized all but two of the six years (2005-2010) covered by the study. Among the reasons for this were government imposed export restrictions and high transport costs associated with illicit road and border taxes that diminished potential input subsidy gains.

The authors conclude that there is a lack of coherence between stated government strategies and the results of policies actually implemented (see Box 4 for the French text).

This sentiment was also expressed in an *Enquête Agricole de Conjoncture* (EAC) report, which noted that sorghum and millet had received less support relative to rice and maize from government programs to intensify production through the use of improved seeds and fertilizers (see Box 5 for exact statement in French).

These are not unjustified comments given the stated crop sector objectives mentioned in various government strategy documents. On the other hand, one must also take into account Mali's overall cereal policy and how well it has done in terms of insuring national food security. For example, a recent assessment of response to the 2008 commodity price crisis in three West African countries, praised Mali for being able to manage the crisis better than the other two countries (Gambia and Côte d'Ivoire):

> …although the suspension of import tariffs may have exerted some downward pressure on rice prices, other factors more effectively explain Mali's better position during the 2007-2008 global food crisis. These factors include more robust rice and coarse grain sectors, a record grain harvest in the 2008 season spurred by good rainfall, burgeoning sorghum production linked to the collapse of cotton for export, and adaptable poorer households willing to switch to coarse grains when rice prices climbed. Further, many of these factors are linked to Mali's relatively good internal transportation network, landlocked nature, and past policy decisions. (Moseley, Carney, and Becker 2010).

Although some of the claims made in this quote are not fully supported when looking at the Malian situation from diverse sources of data, one can still conclude that relative to a number of its neighbors, Mali can be viewed as having already realized important food security benefits from its policies.

Box 4. Observations on How Policy Affects Sorghum and Millet

… le Mali encourage la production de mil et de sorgho mais de manière moins explicite et moins directe que la production de maïs et de riz. L'inclusion tardive (cela s'est produit lors de la campagne 2009/10) du mil et du sorgho dans le groupe des produits soutenus pour un meilleur accès aux intrants ne s'était pas encore traduite en 2010 par des incitations à la production ni même au niveau des grossistes.

Il peut apparaître qu'on n'observe pas de véritable cohérence entre les objectifs de politique affichés et les effets de ces politiques, en particulier à partir de 2009 et 2010 ou les pénalisations sont fortes malgré l'Initiative en faveur des céréales. (Mas Aparisi, Diallo, and Balié 2013, page 38)

Box 5. Government Policy Effects on Maize and Rice vs. Sorghum and Millet

Des baisses importantes de superficies sont notées sur le mil et le sorgho aussi bien comparativement à la campagne précédente que par rapport à la moyenne des cinq (5) dernières années. Cette situation s'explique essentiellement par le retard dans l'installation des pluies. Par ailleurs, il faut signaler que ces deux spéculations semblent souffrir de l'importance donnée au maïs et au riz à travers la politique d'intensification (engrais et semences hybrides) dans le sud du pays. C'est pourquoi Riz et Maïs ont enregistré des hausses de superficies par rapport à 2012/2013 et à la moyenne des cinq ans malgré le démarrage difficile de la campagne (République du Mali 2014, with underlining added).

4. SORGHUM PRODUCTIVITY RESEARCH AND DISSEMINATION STRATEGIES

4.1. Productivity Research Strategies and Results

IER and ICRISAT have been the main actors in Malian sorghum productivity research. ICRISAT focused initially on improving yields but increased attention to other characteristics such as grain quality, nutrition[10], fodder, and local adaptability over time.The IER mandate has beento intensify sorghum production in the Soudanian and North Guinean zones and to maintain current levels of production in the Sahelian zones. Other units of IER have contributed to a better understanding of sorghum productivity indirectly through their focus on agronomic practices, soils, and developing markets.

4.1.1. Sorghum Variety Development Research and Results

Sorghum research initially focused on resolving production constraints such as erratic rainfall, short rainy season, degraded soils, and high costs of inputs through the development of new varieties that exhibited strong yield advantages over traditional varieties. By 1960 local varieties such as Tièmarifing, SH1D3, SH2D2, Gadiaba, and Manganié had been identified by massale breeding and recommended for wide distribution. The most widespread was Tièmarifing for areas with 800 to 1,000 mm of rain per year. Between 1960 and 1974, the best performing variety developed was CE-90 with a 90-day cycle, 2 tons per ha and some resistance to drought. It was distributed widely in Diéma, Nioro, and Cinzana. From 1978 to 1986, sorghum surveys were carried out by IER, IBPGR, and ORSTOM (Clément and Leblanc 1986) to create the Malian Sorghum Collection (CSM varieties). This included a systematic evaluation of more than 1,300 accessions by the different stations and substations for Agricultural Research (Touré 1979; Touré 1980). Many cultivars with yields of 1,500-2,000 kg/ha were identified and diffused (e.g., CSM63, MSC 219, MSC 228, MSC 388, MSC 415, CZ Sèguetana). The collection revealed interesting results for both yield and grain quality.[11] For example, Malisor 84-7 was used by breeders as the stable source of resistance to bugs.

Accomplishments through the 1990s included 13 improvements in local varieties and four key groups of new varieties (IER 2003; Doumbia and Touré 2000) and brought increased attention to the importance of photoperiod-sensitive varieties (Traoré et al. 2000):

- N'ténimissa—a tan colored variety possessing good traits from guinea varieties and high yields—created by crossing local cultivars with guinea and improved Caudatum cultivars.
- Promising guinea tan varieties including two with short cycles (1,700 to 1,900 kg/ha), two with intermediate cycles(1,300 to 1,600 kg/ha), and two with long cycles (roughly 2,000 kg/ha)
- Promising Caudatum varieties with guinea traits including three with short cycles (2000 to 2400 kg/ha); three with intermediate cycles (1,900 to 2,500 kg/ha); and two with long cycles (roughly 1,800 kg/ha).

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[10] See http://www.afripro.org.uk/ for proceedings of the workshop on the proteins of sorghums and millets: Enhancing nutritional and functional properties for Africa. Atokple (2003) focuses on sorghum and millet in West Africa.

[11] Varieties of interest included: : Malisor 84-2 (83-F4-24) Malisor 84-3 (83-F4-23) Malisor 84-4 (83-F4-183) Malisor 84-5 (83-F4-352) Malisor 84-6 (83-F6-173) Malisor 84-7 (83-F6-225) Malisor 92-1 (87-Lo-F4-92) Malisor 92-2 (87-SB-54-2) Dusu Suma (89-SK-F4-53-2PL) and Darilla (89-SK-F4 -184-1PL).

- Photoperiod-sensitive varieties of short stature and populations adapted to different ecologies and photoperiods.

Noteworthy improved varieties mentioned in Diakité (2009) include several of the CSM series, such as CSM 63E (Jakumbe), Tieble, Jigiseme, Tiemarifing, Gadiaba, and Seguétana CZ.

A 1996 assessment of the ICRISAT sorghum and millet breeding program found that[12]:

- farmers' adoption of newly bred varieties, particularly those not resembling the local guinea-type landraces, was very low; Caudatum types—the early focus of ICRISAT research—were often rejected because of poor cooking quality and susceptibility to diseases and pests, and
- farmers preferred purified sorghum landraces selected from local materials; they had only a small yield advantage but slightly earlier maturity.

The ICRISAT assessment report (Yapi et al. 2000) differentiated the two main approaches to sorghum improvement that were pursued by IER and ICRISAT through the 1990s: (1) collecting, testing, selecting, and purifying superior landraces for re-release to farmers, and (2) introducing and crossing exotic germplasm with characteristics thought to be desirable, including short duration, drought tolerance, short plant height, emergence in high temperature, and grain yield. The authors found that adoption rates were substantially higher for the purified landraces, although their yield advantages were often small compared to the potential of exotic germplasm. Often, the yield potential of exotic germplasm was not met because of poor grain quality (losses in milling and storage).

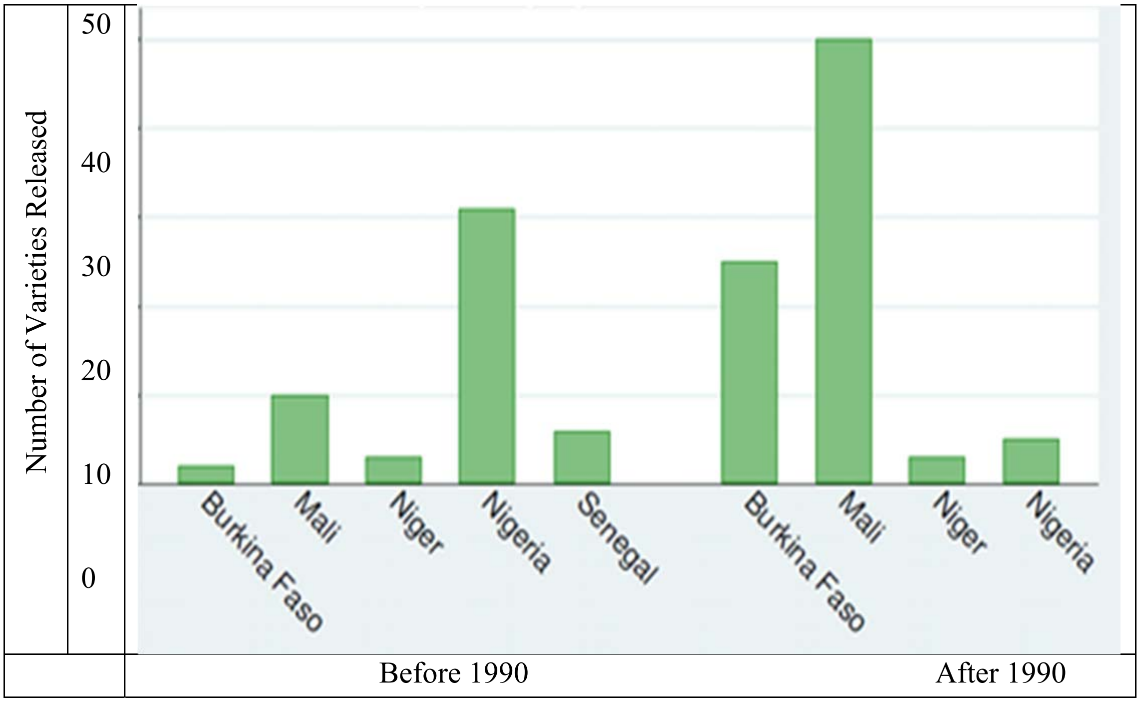
Since the Yapi et al. (2000) assessment, IER and ICRISAT have sought to develop pure Guinea-race varieties and hybrids as well as diversified Guinea hybrids and varieties with varying contributions of Caudatum germplasm. These materials appear to have growth characteristics that are attractive to farmers and sufficiently different from their own materials to encourage use (Weltzien et al. 2006; Weltzien et al. 2008a; Weltzien et al. 2008b).

Although the Yapi et al. (no date) review of millet/sorghum research recommended future work be directed more toward lifting adoption constraints (e.g., soil fertility and general crop management) and less toward additional variety development, investment in variety research continued. IER/ICRISAT, however, began to implement changes in the participatory nature of sorghum research, with multi-locational testing of varieties at an earlier phase of development. They also undertook efforts to link farmer and community organizations more closely to research and to supply seed in a more decentralized way. The new approach appears to better address farmers' preferences and priorities, while meeting other goals, such as farmer empowerment, biodiversity conservation, and poverty-related issues (Weltzien et al. 2006; Weltzien et al. 2008a; Weltzien et al. 2008b).

Illustrating the success of changes in both breeding strategy and the increased focus on participatory breeding, at least 38 major sorghum varieties are currently being disseminated in Mali (Appendix 6). An ICRISAT 2010 regional study of five West African countries showed Mali placing second in number of 1970-1990 sorghum variety releases; for the 1990 to 2010 period, Mali was the best performer (Figure 11).

[12] Many of the points made about changes in breeding strategies here are described in more detail in Smale et al. (2014), which was the principal source for this summary.

Figure 11. Number of Varieties Released per Year before and after 1990



Source: Adapted from Ndjeunga et al. 2012, citing ICRISAT 2010 survey data.

For the entire 1970-2010 period, Mali contributed 60 of the 135 varieties released by the five countries. Of the varieties listed in Appendix 6, 74% have been released since 2000. Hybrids have dominated releases since 2008 when the first Guinea-race sorghum hybrids bred for this region were released. Preliminary evidence demonstrates that these have great potential to generate appreciable yield gains in farmers' fields, across a range of environments, with or without fertilizer (Rattunde et al. 2013).

Maintaining genetic diversity on farms is often considered to be important for ensuring resilience to climatic shocks, local adaptation to heterogeneous production environments, and meeting diverse farming objectives (food, feed, fodder, and sales). Genetic diversity of sorghum has been fostered to date by traditional varieties that are exchanged through farmer seed networks. The quality of sorghum and millet seeds exchanged in traditional networks has been tested and found to be comparable to the quality of foundation seed; overall, farmers recycling of varieties (saving seed for several years) did not markedly alter variety traits in sorghum (Diallo 2009). De facto, farmer-based seed systems are believed to supply by far the majority of annual sorghum seed needs (90-95%). Research has explored farmer-based systems (see, for example, Bazile and Abrami 2008; Coulibaly et al. 2008; and Siart et al. 2008), and the linkages between farmer-based and relatively weak state-based systems, in an effort to better understand the potential to expand the reach of modern seed markets (Smale et al. 2008; Jones 2014).

4.1.2. Agronomic Practices Research and Results

Range of Practices. Yapi et al. (no date) identified soil fertility as a key issue based on a formal survey of farmers who reported overwhelmingly that soil quality was one of the principal constraints slowing adoption of improved varieties. The report called for less expensive fertilizer technologies, more use of available organic materials, land preparation techniques to improve soil moisture, soil enhancing crop rotations and intercropping, and improved weed control.

Many of these topics were already being addressed and some have been the focus of subsequent research projects. The IER's summary of thirty years of agronomic research (IER 2003) mentions recommendations on seeding densities, fertilization using organic and inorganic fertilizers as complements and/or substitutes, crop rotations to increase yields and improve soil fertility, and land preparation methods to increase soil moisture retention; however, there is little information on economic analyses or adoption.

Micro-dosing. Initial results of an Alliance for a Green Revolution in Africa (AGRA) study in Mali (Sogodogo et al. 2013) show that using small amounts of fertilizer placed in the planting holes (rather than larger amounts that are broadcast) can provide significant yield increases over a 3-year period. Doses ranging from 0.4 to 0.8 grams per pocket (33- 53kg/ha, depending on the zone) gave the best results regardless of the crop (Appendix 7). The AGRA micro-dosing program was regional with similar yield results obtained in Niger and Burkina Faso. These studies also found evidence of much higher farm incomes from micro-dosing than traditional fertilizer recommendations (see, for example, Bationo and Egulu 2013; Tabo et al. 2006; Tabo et al. 2007).

The research program included training programs for farmers and extension agents and a warehouse receipts program, illustrating an emerging strategy of integrating activities into the research process to stimulate adoption. A challenge for promoting widespread use of micro-dosing is that it is labor intensive, using as many as 12 man-days of labor per hectare when done manually. Research is underway in Mali to mechanize the process via the introduction of a mechanical seeder that dispenses seeds and fertilizers simultaneously using only one man-day of labor per hectare (Coulibaly et al. 2014b)[13].

Micro-dosing recommendations have grown out of earlier soils research on yield and soil fertility decline among small-scale farmers (e.g., Buerkert and Hiernaux 1998; Bationo and Buerkert 2001). There is not yet evidence from long-term trials that continued micro-dosing for many years can provide a long-term solution to Mali's soil fertility problems. Some fear that it will lead to soil degradation (Breman, Buerkert, and Twomlow personal email exchanges 2012).[14] Others, however, believe that it will enable farmers to build financial capital through increased income and improve their overall farming system (Bationo and Egulu 2013). Should yield response to micro-doses decline, the increased income would permit farmers to gradually raise application rates. It is still not clear, however, if the many farmers who grow sorghum strictly for home consumption will find the gains from micro-dosing an adequate incentive given the additional labor requirements and the need to market a part of their production to cover fertilizer costs.

[13] Some of the economic analysis presented in the report was not clear and needs refinement before establishing potential returns.

[14] Soil degradation could happen, for example, if plant uptake of nutrients continuously exceeds the additional nutrients being added to the soil or if farmers rely only on the micro-dose and do not maintain soil organic matter. From 1962-1987 there was substantial research on the impact of different management and fertilization practices on yields and soil quality (e.g., organic matter content and pH) in Mali and elsewhere in West Africa, with varying estimates of the long-term prognosis for soil degradation using fertilizer doses of 100 kg/ha or more (Pieri, 1989; van der Pol, 1992; Dalton 1996; Ramish 1999). Given that all of these studies found some evidence of soil degradation over time using recommended practices, it seems appropriate to conduct similar longer-term research on micro-dose recommendations.

Crop Rotations. We have not found much discussion of crop rotations or intercropping practices outside of the IER (2003) report. One exception was Staatz et al. 2011 (drawing on Foltz 2010) that mentioned recent experiment station work showing that intercropping sorghum/millet with cowpeas/soybeans could reduce fertilizer applications and costs 33-45% while obtaining sorghum yields comparable to intensive mono-cropping (1.5-3 tons per hectare) and cowpea/soybean yields of 300-500 kg/ha. Intercropping was expected to be particularly appealing to women as they tend to grow these crops already and the introduction of intercropping does not demand increased use of purchased inputs or animal traction equipment. The report also called attention to new cash crop potential using sesame and soybeans as the intercrop.

Soil and Water Conservation. An assessment of the CMDT's 13 year anti-erosion and organic fertilizer programs promoting technologies such as rock lines, living hedges, and animal and green manures found significant increases in cotton yields but not cereal yields. A weakness of the analysis was that control fields were not necessarily at the same level of degradation or risk of degradation (e.g., slope) as the treatment fields—this having been more a problem with cereal than with cotton fields. Farmers' opinions about the differences in yields before and after were much more favorable for cereals than the statistical analyses.

A meta-analysis of 63 studies on conservation farming practices used on coarse grain plots in West Africa examined the evidence on yield differences between treated and control fields (Bayala et al. 2012).[15] Key findings included significant variability in maize, sorghum, and millet yield response (and hence risk) with all the practices examined. For most crops, green manure provided the highest yield differences, followed by mulching, with larger yield differences in lower rainfall zones and when the fields were initially more degraded.

IER conducted substantial research on tied ridges (*aménagement en courbe de niveau* in French) in the late 1990s and early 2000s. The practice creates earthen ridges along the contours using an ox-drawn plough. Crops are grown on ridges along the contours while a permanent grass cover maintains the ridges. The rainwater is kept on the field between the ridges, permitting it to filter into the soil. The additional water infiltration is equivalent to 10% of the total rainfall. Benefits include a 30% increase in yields and lower annual yield variation. Three journal articles summarize the findings as of 2009, each focusing on a different aspect of the technology—yield impacts (Gigou et al. 2006), soil moisture (Kablan et al. 2008), and soil organic carbon (Doumbia et al. 2009). The published articles focus on the technical aspects with little attention to economics or adoption; but Gigou et al. (2006) do note that widespread adoption is hindered by farmers' need for technical assistance in marking out the contours.

Climate Change. A variety of research efforts is taking climate change into account. Kouressi et al. (2008), for example, discuss research on the role of genetic diversity, length of crop cycles, and rainfall in different agroecological zones. A 2013/14 report (Coulibaly et al. 2014a) for the IER *Adaptation de l'Agriculture et de l'Elevage au Changement Climatique* project mentions a number of research results for agronomic approaches to improving cereal productivity. Although none of these technologies appears ready for wide dissemination, the

[15] Sixteen of the 63 studies were in Mali. Practices covered in Mali included parkland trees associated with crops, coppicing trees, green manure, mulching, crop rotations and associations, and soil and water conservation practices.

report illustrates that project funding is permitting IER to conduct research on organic fertilization, land preparation, mechanization of seeding, and seed treatments from a climate change perspective. Results include:

- A 100% increase in sorghum yields due to an application of 2.5 T/ha of manure plus 5 kg of inorganic fertilizer (other tests adding compost and organic fertilizer manufactured in Mali gave even greater yield increases), and
- Significant yield increases due to soil moisture retention practices during a poor rainfall year (e.g., seeding on straw, with plowing, on ridges, and on tied ridges at the end of the season) compared to seeding in the absence of any plowing or other practices (details in Appendix 8).

Also of interest for sorghum were tests of seeders with different combinations of inputs. Mechanical seeding with no seed treatment and no fertilier yielded 783 kg/ha, while nontreated seeds and a micro-dose was 23% greater than the control and treated seeds and the micro-dose was 62% greater. The best yields (2,199 kg/ha) were obtained with the *semoir multirang* (which had separate compartments for seed and fertilizer), treated seed, and the micro-dose (details in Appendix 9)

4.1.3. Sorghum Pest Management Research and Recommendations

Research on reducing the productivity impact of plant diseases included breeding for resistance, seed treatments, and insect inventories. Examples of breeding successes reported by IER include:

- CSM 388 which resists leaf diseases such as sooty stripe and anthracnose;
- N'ténimissa, CSM 415, CSM 417, and 96 SB-CS-F6-15 which are resistant to fungi such as anthracnose of the leaves and of the grain;
- CSM 63 and ICSV 1001-BF which are tolerant of long smut; and
- ICSV 1001-BF, L30, E 35-1, and Malisor 84-2 which perform well when grain moisture is high.

IER-recommended seed treatments include:

- A mix of benomyl-thiram-heptachlore to strengthen plants at emergence and provide a 15% increase in yield, and
- Apron + 50 DS and Vitaux to control covered smut; also recommended are various combinations of local plants such as Nguo + Néré + Lonchocarpus; Nguo + Diro + Lonchocarpus; Nguo+Samakara+Lonchocarpus; Nguo+Diro; Diro+ Néréfara +Nguo.nguo.

Entomology research included an inventory of insects harmful to sorghum as well as a study on their population dynamics. Among the principal sorghum predators were midge, head bugs, and shoot fly. Losses in sorghum quality due to head bugs were also documented.

Weed control research focused on striga (*Strigahermonthica*). Recommendations, in addition to improving soil fertility through agronomic methods mentioned above, included:

- Intercropping of sorghum and groundnuts or sorghum and cowpeas;
- Planting local varieties that were tolerant of striga such as Seguétana, Framida, SRN 39, CE 151, ICSV1063, 87-Lo-F4-155, 87-Lo-F4-92, 84-SB-F4-16-4 and Malisor 84-1; and
- Chemical treatment using 2 liters/hectare of 2-4 D to destroy stands of striga that are evident 70 days after planting.

We found no information on how widespread the adoption of these various recommendations were.

4.2. Dissemination Strategies for Improved Sorghum Technologies

There are numerous references to low adoption rates of improved cereal varieties and the need for better dissemination of research results for Africa in general (e.g., Tripp and Rohrback 2001; Minot et al. 2007; Maredia et al. 1999; Walker et al. 2014). For Mali in particular, weak research/extension linkages, weak seed production and distribution services, and underfunding of extension were discussed earlier and have been well documented (Tyner et al. 2002; Kelly et al 2005; Staatz et al. 2011; Stoop 2002 and 2003; Christiansen and Cook 2003; Simpson and Dembélé 2010). Since 2000, two dominant topics in discussions of dissemination strategies for improved sorghum technologies have been (1) seed production/delivery systems (farmers cannot buy seeds that are not on the market) and (2) market demand for sorghum. The first topic deals with supply constraints and the second with demand constraints.

4.2.1. Addressing Supply-side Dissemination Constraints

Christiansen and Cook (2003) focused on seed supply and marketing issues. Their recommendations differed by crop, recognizing that for non-hybrid improved varieties of millet and sorghum, both tradition and economics worked against seed market development. Their suggestion was to use subsidies to familiarize farmers with improved varieties (e.g., small packs, coupons, loan programs) as an initial step. Diakité et al. (2008) describe seed sector value chains in Mali a few years later, noting that both seed demand and supply continued to be unresolved issues:

> There is no consensus on whether lack of effective demand or insufficient seed supply is the foremost constraint to the use of certified sorghum and millet seed in Mali. Effective demand of farmers remains poorly understood. Even if demand is limited, however, it is evident that the supply of certified seed in many rural areas is hard to find. Total supplies of R1 and R2 seed produced represent an estimated 2-5% of the area sown to the crops each year (Diakité et al. 2008, page 28).

Although a variety of projects and programs have been developed to stimulate sorghum seed production and marketing, no robust, sustainable system has emerged. Since 2009, there has been renewed attention to seed production and dissemination policy in Mali with the issuance of a number of regulations (République du Mali 2012):

- *le Document de politique semencière adopté le 23 décembre 2009* (Document on seed policy adopted 23 December, 2009)*;*
- *la Loi N° 10- 032 /DU 12 JUILLET 2010 Relative aux Semences d'Origine Végétale* (Law number 10-032 of 12 July, 2010, relative to seeds from plant origins);
- *l'Arrête Interministériel N°10- 2114 /MA-MEP-MEEP-SG du 16 JUILLET 2010 Déterminant les métiers agricoles* (Inter-Ministry Order No. 10-2114/MA-MEP-MEEP-SG of 16 July, 2010, Determining agricultural vocations);
- *le Décret N° 10- 428 /P-RM DU – 9 AOUT 2010 Fixant les modalités d'application de la Loi relative aux Semences d'Origine Végétale* (Decree No. 10-428/P-RM of 9 August 2010, fixing the modalities for applying the law relative to seeds of plant origin);

- *le Manuel de procédure de certification des semences AVRIL 2010* (The manual of seed certification procedures, April 2010)*;* and
- *le Manuel de procédure d'inscription au catalogue officiel des espèces et variétés AVRIL 2010* (Manual of procedures for registering in the official catalog of species and varieties, April 2010).

Smale et al. (2014) report that according to ICRISAT (2013), sales of improved sorghum seed produced by the farmer organizations partnering with ICRISAT and IER (excluding quantities produced directly by private companies and non-partner farmer organizations) had reached 70 tons, of which 20 tons were hybrid seed. There is also evidence of private companies contracting with farmer organizations to meet the growing demand for improved seeds that respond to the diversity of farmer needs. Since 2007, the Alliance for a Green Revolution in Africa (AGRA) Scaling Seeds and Technologies Partnership in Africa has provided grant support to six organizations successfully supplying Malian farmers with improved seed (five private firms and one cooperative).[16] A 2011 review of leading firms in the Malian seed sector noted important expansion during the previous five years, while stressing the need for an integrated approach combining production and marketing skills (Dalohoun et al. 2011). The authors also noted that governments can give entrepreneurs room to grow by supporting certification, organizing national seed fairs, and supporting the financial sector, but need to be careful about overly restrictive legislation such as requiring that all marketed seed be certified.

4.2.2. Addressing Demand-side Dissemination Constraints

Suggestions for increasing sorghum demand included developing cereal processing industries, improving on-farm storage and credit systems so farmers could sell when prices were higher, and policy interventions to reduce input prices so sorghum could be sold profitably at lower prices (Yapi et al. no date; Vitale and Sanders 2005; Sanders and Shapiro 2006). INTSORMIL, the USAID-funded millet/sorghum project conducted in collaboration with IER, was a strong proponent of this market approach, supporting farmers with extension advice and assistance to purchase inputs and access output markets. A key feature of the program was the creation of cereal banks and a warehouse receipt program that permitted farmers to delay crop sales until prices were favorable. In 2010, after six years of activity, USAID/Mali (2010) reported that results were positive for most participants, yet the magnitude of the scaling-up problem becomes evident when one realizes that the estimated 4340 ha of millet and sorghum cultivated by program participants represented roughly 0.16% of Mali's total millet/sorghum area for that year. An INTSORMIL report on details of the 2010/11 season showed relatively good millet results but illustrated that sorghum results were mixed across intervention zones with problems of poor seed quality, flooding, and incomplete adoption of recommended practices reducing the yield advantages and economic returns (Coulibaly, Kumaraswamy, and Sanders 2013).

In a complementary effort, the Laboratoire de technologie alimentaire (LTA) of IER has conducted research on cereal processing, developing recommendations for use of sorghum in various types of pastries, breads, crackers, and juices. The 2003 IER summary of thirty years of research noted, for example, that a local processor was marketing a cracker (Deli-ken) using sorghum for 20% of the flour and other crackers had been developed using only sorghum flour. Breweries were also using varieties such as Malisor 92-1 and Foulatiéba.

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[16] Personal communication from the project chief of party, Richard Jones.

4.2.3. Other Dissemination Strategies

While programs that focused on seed supply and output demand dominated dissemination strategies, IER and ICRISAT continued to improve the chances for technology adoption by fine tuning their research protocols so that they involved more farmer participation at earlier stages in the research process (see Weltzien et al. 2006, 2008a, 2008b, discussed above)

A number of NGOs have also contributed to dissemination efforts by supporting demonstration and test plots. For example, from 2010-2012, Sasakawa Global 2000 (SG2000) supported farmer demonstrations/field trials using 6-8 kg/ha of CSM 63-E (a variety preferred by processors) in combination with fungicide and 50 kg/ha each of DAP and urea. Participating farmers received credit for the inputs. SG2000 monitored the fields, collecting data on yields, costs, and returns. Average 2011 yields (weighted by size of parcel) for 20 farmers in the Ségou Region were 1.04 tons/ha and the average benefit/cost ratio (calculated as the ratio of the value of production minus the cost of credit to the cost of credit) was 2.9. Fifteen of the twenty farmers had benefit cost ratios above 3, but the average was pulled down by two farmers with negative returns (SG2000 2013).

The World Bank's PASAOP contained components to better integrate research and extension. It created competitive processes for obtaining research funding and involved community representatives who would be end users of research results (e.g., farmers, processors) in the review process. The program has had mixed reviews in terms of its contribution to improved dissemination of results and end-user involvement (Kelly et al. 2005; Simpson and Dembélé 2010). More recent World Bank programs such as the 2010 PAPAM did not include any direct financing for extension, nor was core funding for the provision of extension services from other donors identified.

A *Conseil Ouest et Centre Africain pour la Recherche et le Développement Agricoles* (CORAF/WECARD)[17] regional project has supported integrated platforms that bring together a variety of seed sector actors (farmers, seed producers, input dealers, cereal processors, etc.) who work collaboratively to test and disseminate improved technologies. For example, they sponsored comparative tests of sorghum varieties using a mother/baby protocol to confirm variety productivity and farmer interest. The results of the mother trials identified Sangatigri, Wassa, Siguifa, and Jacumbe listed in Appendix 6 as particularly productive varieties. It is not clear from the project report how well integrated these tests were with the IER/ICRISAT breeding program.

[17] The project name was : Unlocking the opportunities to enhance sustainable seed systems of staple crops (sorghum, pearl millet, maize, cowpea, and groundnut) to improve food security and agricultural production in West and Central Africa; information in this paragraph comes from the final project report for Mali (CORAF/WECARD 2014).

5. ADOPTION OF SORGHUM TECHNOLOGIES AND AGRONOMIC PRACTICES

An overview of the wide range of factors affecting adoption was presented in conjunction with the earlier discussion of sorghum area and production trends. Here we look at national surveys and targeted studies devoted to measuring adoption rates.

5.1. National Data on Adoption

A review of the 2004 agricultural census and recent EAC reports provides a general picture of the state of agricultural technology adoption in Mali. The census used a nationally representative sampling frame statistically accurate at both the Regional and *Cercle* levels; EAC surveys are representative only to the Regional level due to a smaller sample size.

5.1.1. Improved Varieties

Farmers' 2004 census declarations on use of improved seed varieties (all crops combined) show high variability by region, with the major coarse grain producing region of Sikasso being far ahead of other regions (38% of cultivated area), followed by Koulikoro (17%) (Table 4). Results by gender of the household head showed that 83% of male-headed households used improved varieties in Sikasso while only 45% of female-headed households did. Nationally, 24% of male-headed households used improved seed, but just 7% of female-headed households, illustrating how much further up the adoption ladder the Sikasso Region is. The census data did not disaggregate improved seed use by crop; but the majority of reported use is most likely for maize, rice, and cotton.

Information on improved seed is not found regularly in EAC reports; but when it was reported, it was available by crop. The most recent report with such information covered 2007/08, showing that 13% of sorghum area had been planted with improved varieties. This percent included all declarations of improved varieties having been purchased as first-generation seed for 2007/08 (1.6% of total sorghum area) as well as those purchased some years earlier with seed saved for re-planting. Replanting is not recommended for hybrids, but the data does not differentiate between hybrids and open pollinated varieties. This result is similar to the 14% reported for all crops combined in the 2004 agricultural census but quite different from the estimates reported in the targeted adoption studies reviewed below.

Table 4. Hectares Planted with Improved Seed, 2004

Region	Improved Varieties Hectares	Percent of Total Hectares
Kayes	22,941	8.5
Koulikoro	109,617	16.7
Sikasso	276,242	37.8
Ségou	66,056	8.4
Mopti	9,044	1.4
Tombouctou	1,134	1.3
Gao	1,313	1.9
Bamako	1,268	19
Nationally	487,616	14.9

Source: République du Mali 2007 (see Appendix 10 for the full table of results).

Table 5. Percent of Cultivated Cereal Area Having Received Fertilizers, 2004

Region	Percent Organic	Percent Inorganic	Percent Both	Total Percent Fertilized
Kayes	20.5	2.3	2.1	24.9
Koulikoro	32.6	6.3	9.3	48.2
Sikasso	13.0	25.9	30.5	69.4
Ségou	41.0	5.7	7.7	54.4
Mopti	47.5	2.0	1.0	50.5
Tombouctou	29.6	4.2	4.0	37.8
Gao	2.9	0.7	0.1	3.7
Bamako	44.3	10.9	31.6	86.8

Source: From Table 77, République du Mali 2007.

5.1.2. Use of Fertilizers

Sikasso exhibits the highest rate of inorganic fertilization (26% of cultivated area) and highest rate of combined use of organic and inorganic fertilizers (31%)—hence, at least 57% of all cultivated area in Sikasso received some inorganic fertilizer. Koulikoro and Ségou are far behind in the use of chemical fertilizers, but have a larger share of land benefiting from application of organic fertilizers (Table 5).

The 2013/14 EAC report reflects higher levels of fertilizer use under the government subsidy program (roughly 25% of the price is subsidized). Nationally, 48% of farm households used some type of fertilizer: 18% used organic fertilizers, 25% inorganic fertilizers, and 5% used both. Average use per hectare was 36 kg (up from only 19 kg in the prior season, which had poor rains). The Sikasso Region used 76% of all fertilizers consumed, followed by Koulikoro (14%) and Ségou (6%). Average use per hectare in Sikasso was 85 kg, reflecting the importance of fertilizer use on cotton in this Region.

5.1.3. Agronomic Practices and Equipment Ownership

Other insights about adoption of some of the agronomic recommendations come from statistics in the agricultural census about intercropping; a practice recommended by research for improving sorghum yields and reducing weed problems. In 2004, 80% of all fields were planted in a single crop. Fields planted in two or more crops were most common in Mopti (37% of the region’s cultivated area), followed by Koulikoro (22%), Sikasso (19%), Ségou (16%) and Kayes (15%). The practice is more popular in the dryer production zones.

Many of the recommended agronomic practices require access to animal traction equipment. In 2004, the coarse grain producing regions had relatively good access to mechanized plowing. Sikasso farmers reported using improved land preparation equipment (owned, borrowed, or rented) on 94% of their cultivated area and Koulikoro farmers reported 83% of land preparation done with animal traction. Use of motorized equipment is at an early stage (<2% of land in these regions). Nationally, 43% of farm households owned at least one complete set of functional equipment.[18] Sikasso was the best equipped (64,6%), followed by Ségou (60,2%), Koulikoro (55,4%), Mopti 37%, and Kayes (18%).While national and regional statistics do not provide specific information about sorghum, the high rates of fertilizer adoption and animal traction use in the main coarse grain production areas suggests a link between the technologies and cereal production.

5.2. Targeted Adoption Studies of Sorghum Technologies and Agronomic Practices

5.2.1. Adoption Rates for Improved Sorghum Varieties

There have been intermittent bursts of enthusiasm across Africa for doing returns to research analyses when funding for agricultural research is under pressure (e.g., Yapi et al. no date and 2000; Maredia, Byerlee, and Pee 2000; Ndjeunga et al. 2012; Dalton and Zereyesus 2013; Smale et al. 2014).[19] A benefit of these analyses is that most included targeted studies to measure adoption. Although none of the results is based on a nationally representative survey such as the agricultural census and the EAC, they still provide important insights into adoption of improved sorghum varieties for some of Mali's principal production zones.

The most recent study (Smale et al. 2014) interviewed 2,430 households in 58 villages where IER/ICRISAT worked directly or indirectly through farmer organizations to test materials over a number of years. In this relatively favored environment (the Sudan-Savannah zone) where one would expect better than average access and adoption, improved varieties were used on 20% of sorghum area in 2009 and gradually increased up to 24% by 2013, with the largest increase between the fourth and fifth year. These estimates were based on names reported by farmers and checked with IER/ICRISAT databases and farmer recall. Thus, they include first-generation and advanced-generation improved seed. Adoption rates measured as the percent of all sorghum plots per village were normally distributed from zero to over 80%.

A regional (five-country study) by ICRISAT (Ndjeunga et al. 2012) conducted in 2010 used expert opinion to estimate adoption rates that appear to cover the entirety of each country.[20]The study divided adoption into two groups: (1) all varieties released since 1970 and (2) only newer varieties released since 1990. It was estimated that the former were being cultivated on 33% of Mali's sorghum area in 2010, while the latter were cultivated on 21% of area. Appendix 11 lists estimates of area covered by variety, illustrating how the 33% was reached and showing comparative results for Niger (15%) and Senegal (41%). Given the methodology described, there should be some information available from this study on the geographic distribution of adoption within Mali, but details are not found in the report.

An ICRISAT review of breeding research and adoption for West Africa (Camara, Bantilan, and Ndjeunga 2006), reported that Mali, along with Cameroon and Chad had been increasing the percent of sorghum area cultivated with improved varieties regularly over the 1990 - 1995 period.

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[18] A complete set of equipment was defined as any one of the following combinations: 2 oxen, one cart; 1 donkey and at least one plow and a cart; 1 horse and at least one plow and a cart; 1 camel and at least one plow and one cart; 1 multiculteur and a cart.

[19] A summary of the results of studies on returns to sorghum research can be found in Smale et al. (2014).

[20]Information on how the adoption estimates were made is a bit sketchy (details in Appendix 12).

The Mali analysis was based on adoption estimates from a 1996 farm survey by Yapi et al. (no date) which determined the following progression of adoption:[21]

- 1990: Improved cultivars 17% of land area
- 1991: Improved cultivars 19%
- 1992: Improved cultivars 20%
- 1993: Improved cultivars 22%
- 1994: Improved cultivars 24%
- 1995: Improved cultivars 29%

Unlike the ICRISAT 2010 estimates, these estimates were based on farm surveys, but limited to the regions of Koulikoro, Mopti, and Ségou regions where sorghum and millet were important crops but also zones that had lower rainfall and were more likely to benefit from the newer short-cycle and drought resistant varieties. In retrospect, the distribution of cereal production trends from 1990-2000 suggests that the omission of the Sikasso Region from this analysis was unfortunate, as Sikasso represented 27% of sorghum area and 30% of national production and has been increasing its share of production; Koulikoro was close to Sikasso with 19% of area and 29% of production (suggesting greater intensification than Sikasso), but Ségou and Mopti had smaller and declining shares of area and production from 1970s through 2000.

Although Yapi et al. (no date) reported an impressive list of 47 different sorghum varieties, the researchers were able to determine that many were simply different names for the same variety. The area estimates are based on farmers' reported use of the following eight varieties, which were recognized by researchers and extension agents as improved varieties: CSM63-E, ICSV1063BF, Séguètana, CE151, ICSV1079BF, Tiémarifing, CSM388, and Guéfoué. Separate rates were estimated for the three regions covered with Koulikoro exhibiting the highest adoption rates moving from 20 to 30% over the six-year period. Ségou and Mopti were lower, moving from 14 to 29% and 14 to 23%, respectively.

Sanogo and Teme (1996), mentioned in Ndeunga et al. (2012), focused on the CE151 sorghum variety only, and found a 36% adoption rate for it. Ndjeunga and Bantilan (2005) reported a 33% adoption rate for sorghum in 2002; however, villages in the sample were purposively selected to get a combination of those near/far from markets and sources of input supply. Consequently, it is not clear what the 33% aggregate adoption rate for the entire survey really represents given the lack of a weighting metric. Similar to the Yapi study, villages were outside the Sikasso Region, with results primarily relevant to dryer zones.

Employing a different approach to estimation, Diakité et al. (2008) used data for production of certified seed from 1996 through 2006. Certified seed sold in each year represented 2-7% of the sorghum area planted. Using an assumption that farmers replaced their certified seed in the fourth year, the authors estimated that the area covered by certified sorghum seed increased from about 8% in 1996 to 16% in 2006—much lower than the Yapi et al. (no date) estimates, which were already at 29% in 1995.

[21] The sorghum adoption estimate was based on information obtained from a sample of 299 farm households, of which 213 (71%) had used improved sorghum varieties during the recall period; this data gave an adoption rate in terms of area cultivated from 17% to 28% between 1990 and 1995 for the three regions covered (Mopti, Ségou, and Koulikoro) (Yapi et al. 2000). See Appendix 13 for details.

In an assessment of the adoption of improved rice and sorghum varieties, Diakité (2009) found on overall adoption rate of roughly 20% across 10 villages and 1047 farmers in the zones of San and Sikasso. Major varieties included N'ténimissa, CSM 388 (Jigiseme), ICSV1063, and Malisor 92-1. Diakité estimated that while 87% of rice area and 100% of cotton area in Mali were already planted to improved varieties in 2009, the share of improved varieties in sorghum area was only 18%. He cited the lack of an organized production and marketing channel for sorghum, which is a more traditional food staple, as a principal constraint.

The conclusion from this review of adoption rates for improved sorghum varieties is that there is a need for more attention to monitoring adoption on a regular basis. The EAC surveys (which no longer collect data on improved varieties) and the agricultural census results suggest lower adoption, but are very imprecise about what varieties are actually being reported and whether they really are improved varieties. The adoption estimates from targeted studies tend to be higher, but given sampling methods for the survey-based approaches and the methodological fuzziness of methods relying on expert opinion, it is difficult to know if these results are valid national estimates. If the more recent 2012 estimates are accurate, then we are left asking why there has been no improvement since the Yapi et al. (no date and 2000) estimates given the relatively high rate of new releases since that time.

5.2.2. Adoption Rates for Fertilizer and Agronomic Practices

Supplementary information on adoption of soil fertility measures is limited, but Ndjeunga and Bantilan (2005) reported the percent of farmers using the techniques listed in Table 6.

Given the sampling frame, these results seem to represent the Regions of Kayes, Koulikoro, Ségou, and Mopti but not Sikasso, where both organic and inorganic fertilizer use is higher because of cotton production. CMDT monitoring and evaluation data for the 2006/07 cropping season showed that 5% of farmers used chemical fertilizers on sorghum with an average of 28 kg/ha of urea and 38 kg/ha of NPK. Average sorghum yields for all farmers (regardless of fertilizer use) were 814 kg/ha.

5.3. Understanding Adoption Motivations and Constraints

Information on reasons for adoption was available in several of the returns to research studies that conducted farm level interviews. Common reasons for adoption and constraints to adoption were reported by Yapi et al. (no date and 2000) and Camara, Bantilan, and Ndjeunga (2006) (Table 7).

Yapi et al. (no date) noted that the relative importance of reasons for adoption differed by region, with Ségou and Mopti—the dryer of the three zones—citing early maturity as the most common reason and respondents in Koulikoro mentioning productivity more frequently. All regions put lack of information and seed availability as the two most important constraints, but starting with the third constraint there were regional differences.

Table 6. Use of Soil Fertility Management Techniques

Soil Fertility Management Technique	Percent of Farmers Reporting Use	Soil Fertility Management Technique	Percent of Farmers Reporting Use
Mineral fertilizers	50.5	Crop association	25.5
Organic fertilizers	79.8	Crop residues	13.1
Compost	--	Other	--
Fallow	32.4	No method	1.2
Crop rotation	30.2	Sample size	321
Green manure	--		

Source: Ndjeunga and Bantilan (2005) (not clear if blanks are missing data or zero levels of use).

Table 7. Reasons for and Constraints to Adoption

Reasons for adoption	Constraints to adoption	Source/comment
Short cycle (81%)	Lack of information about the existence and how to use different varieties (66%)	Yapi et al. 2000 survey conducted in 1996 in Koulikoro, Ségou, and Mopti Regions
Yields (72%)	Seeds are not available (52%)	
Food quality (29%)	Soils are too poor for sorghum (13%)	
Striga resistance (13%)	Preference for local varieties (14%)	
Early maturity (25%)	Lack of seed (28%)	Camara, Bantilan, and Ndjeunga (2006) synthesis across multiple studies for WCA for millet and sorghum…not specific to Mali or to sorghum
Food quality (23%)	Lack of fertilizer (22%)	
Productivity (22%)	Lack of information (16%)	
Disease/drought resistance (16%)	Birds (9%)	
Ease of threshing (5%)	Preference for local varieties (7%)	
Farmers' experience (3%)	Productivity (3%)	
Alternate sources of income (3%)	Poor market (3%)	
Number of sorghum varieties stocked (3%)	Not efficient (3%)	
	Other (3%)	
	Excess rain (3%)	
	Cost of grinding (3%)	

Sources: Yapi et al. (2000); Camara, Bantilan, and Ndjeunga (2006).

Poor soils were mentioned almost exclusively in Mopti. Ségou was the dominant region mentioning a preference for local varieties. Koulikoro farmers were most frequent to mention the problem of high fertilizer demand for improved varieties, bird damage, labor shortages, and storage problems. A geographically limited but more recent survey in the Koulikoro Region (Diola and Mande) found farmers gave highest priority to varieties that were well adapted to their production zones, but also considered cooking quality and drought resistance as important (Diallo 2009).

Although farmers did not indicate that they selected improved varieties for economic reasons, Yapi et al. (no date and 2000) used crop budgets to illustrate that the improved sorghum varieties had production costs per kg of sorghum that were 14-16 FCFA/kg lower than those for local varieties.[22] This was equivalent to a 20-25% reduction in unit costs of output that could be attributed to the improved varieties. In the absence of cash constraints, the lower unit costs should have encouraged adoption; however, adoption did require cash outlays at planting time for seed, insecticide, farm yard manure and—for a few of the varieties—plowing with animal traction equipment.

Yapi et al. (no date) looked at correlations between the decision to adopt improved varieties and a number of household characteristics (Table 8). Across the three regions covered by that study, the education of the household head was positively correlated and number of years of farming experience negatively correlated with adoption. This was interpreted as younger household heads being those with less experience yet having more education—suggesting that the combination of youth and education makes individuals more amenable to experimenting with new varieties. Mopti had the fewest characteristics correlated with adoption (education of the household head, size of the household, and membership in a producer organization). In Ségou, contact with an extension agent, access to more land, and use of inorganic fertilizers were positively correlated with adoption. In Koulikoro almost all the characteristics had positive correlations with adoption, with the exception of years of farming experience (negatively correlated), use of inorganic fertilizers (no correlation), and use of organic fertilizers (negative correlation suggesting that farmers using more organic fertilizers were less likely to use improved seeds).[23] More recent studies focusing on small geographic areas have been summarized in Smale et al. (2014) showing that sorghum test activities and better access to input markets can stimulate adoption and that drought encourages farmers to increase the diversity of varieties planted.

Yapi et al. (2000) also reported that farmers' primary source of seed and of information on seed varieties was other farmers (61% of responses) (Table 9). Only in the Ségou Region did extension services play a significant role providing 50% of the sample with seed information and 44% of the sample with improved seeds. Second in importance for the overall sample were NGOs followed closely by extension services. Studies by Siart (2008); Smale et al. (2008); Smale, Diakité, and Grum (2010); and Jones (2014), among others, confirm the continued role of farmer-based exchanges (occurring both in and outside of markets) in providing millet and sorghum seed to farmers, the importance of women vendors in these markets, and the close relationship between grain and seed markets.

Recent survey data (collected in villages where IER/ICRISAT generally have a presence) confirmed that both Malian men and women are growing sorghum and use rates for improved varieties and hybrids do not differ meaningfully between men and women plot managers (Smale et al. 2014). However, women represent only about 10% of sorghum plot managers, and women's plots are on average less than half the size of men's. The same study found evidence of growing seed purchases, with about a third of the seed of improved varieties originally obtained through cash purchase. This finding is significant, given that previous research has underscored the dominant social norm of *gifts* or saved seed as the primary means of acquiring seed. Monetization of exchanges is important if farmers are to purchase hybrid seed regularly.

[22] The two sources reported slightly different cost reductions/kg; 14 FCFA/kg for the no date and 16 FCFA/kg for the 2000 version.

[23] We think Table 8 is an accurate representation of the Yapi et al. (no date) results, but there was often not a clear distinction in the text between no correlation (which we interpret to mean that the correlation was not statistically significant) and the negative correlations (which in some cases may also not have been statistically significant).

Table 8. Correlations between Adoption of New Varieties and Household Characteristics by Region

Characteristic	Mopti	Ségou	Koulikoro
Education of household head	+	+	+
Years of farming experience	- (n.sig)	- (not sig.)	-
Population of household	+	0	+
Number of active workers in household	0	0	+
Member of a producer organization	+	0	+
Had contact with an extension agent	0	+	+
Owns agricultural equipment	0	0	+
Land availability	0	+	+
Use inorganic fertilizers	0	+	0
Use organic fertilizers (manure)	0	0	-

Source: Adapted from Yapi et al. (no date), pages 16-17. Based on 1996 survey data.

Table 9. Sources of Seeds and Seed Information

	Mopti		Segou		Koulikoro		All three regions	
	Variety info	First seeds	Variety info	First seeds	Variety info	First seeds	Variety info	First seeds
Sources								
Other farmers	86%	95%	6%	11%	66%	62%	61%	61%
Extension agents	9%	5%	50%	44%	8%	9%	14%	13%
Other villages	0%	0%	0%	6%	4%	7%	1%	1%
Seed service	5%	0%	33%	39%	1%	0%	7%	10%
NGOs	0%	0%	11%	0%	21%	21%	16%	15%
Local markets	0%	0%	0%	0%	0%	1%	0%	1%

Source: Yapi et al. 2000.

Ndjeunga and Bantilan (2005) estimated the probability of adopting improved varieties of sorghum using a logit regression analysis with a large number of socio-economic variables; [24] only two were statistically significant: location in the higher rainfall Guinean zone and proximity to a seed multiplication or distribution center. The same study presented two separate logit analyses of the decision to use organic and inorganic fertilizers. The probability of using organic fertilizers was positively associated with household size, cotton production, owning an oxen drawn cart and being in the lowest wealth category; being in the highest wealth category was negatively associated with use of organic fertilizers.

For inorganic fertilizers, larger farm size and location in the higher rainfall Guinean zone were the only two significant variables—both positively contributing to adoption. Farm size was represented in a quadratic form so at some point larger farm size will start to have a depressing effect on the probability of adoption (i.e., there is less incentive for larger farms to intensify).

[24] Variables used included: age of the household head, household size, education; ownership of productive assets (carts, land, cattle stocks); participation in cotton production; proximity to seed multiplication/distribution centers, input/output markets, and a major road; wealth status (determined using survey data), and rainfall zones (Sahel, Sudanian, Guinean).

6. SUMMARY OF KEY FINDINGS AND IMPLICATIONS

The purpose of this literature review was to describe how Mali is currently performing in terms of sorghum productivity, how the sector got to where it is today, and what can be done to further develop it.

6.1. Supply, Demand, and Prices

Domestic sorghum supply has increased significantly over time, with average annual production from 2000-2013 more than double what it averaged from 1964-1999. Production is concentrated in four regions Sikasso (30% of national production), Koulikoro (29%), Kayes (19%), and Ségou (17%). Given more diversified cropping systems in Sikasso, sorghum represents only 39% of that region's cereal production, while it is 63% of Kayes' production and 47% in Koulikoro. These two perspectives – national and regional – both need to be considered when designing cereal research, policies, and extension programs. Despite aggregate growth in sorghum production, average yields and sorghum's share of total cereal production are declining. Sorghum markets remain poorly developed, with an average of only 10 to 20% of production thought to be marketed annually.

Like supply, demand for sorghum has also increased but it is a declining share of cereal demand as consumer preferences shift away from sorghum toward rice and maize. Future growth in demand is expected to come primarily from animal feed manufacturers and neighboring countries with structural food deficits.

For the most part, commercial market transactions determine consumer and producer prices of all cereals; but given the sensitivity of national food security concerns the GOM does play a role in stabilizing prices. This can involve limiting exports when supplies are low and encouraging increased production through input subsidies. Although Mali has a good database on cereal market prices, analyses of these data are limited resulting in a poor understanding of trends in marketing margins and elasticities of sorghum demand and supply.

6.2. Drivers of Sorghum Production Trends

GOM policies, programs, and investments influence farmers' decisions about how much sorghum to grow. Although all cereal sectors benefited from the cereal market reforms that were implemented from the mid-1980s through the 1990s, there was disappointment with the extent of farmers' coarse grain supply response to reforms. In addition, the GOM has done some backsliding by unofficially constraining regional coarse grain exports when consumer prices spike in Bamako (e.g., 2007 and 2008). While this may protect consumers from rising prices, it also reduces the supply response by sending inappropriate signals to farmers.

Cotton policy is also a driver of sorghum and maize production decisions, with farmers changing area planted to cereals in response to cotton prices, payment schedules, and inputs made available through the cotton companies. Although sorghum has benefited from cotton/cereal spillovers, it was on a relatively limited scale compared to maize, which was the focus of a cereal promotion program introduced in the mid-1980s when improved maize cultivars were released and the CMDT provided farmers with cereal fertilizers. The greatest challenge to extending improved sorghum varieties in the cotton zone at present is the continued uncertainty about cotton sector privatization. For some farmers this has encouraged more focus on cereals, but for the vast majority of farmers who do not have the resources to access inputs without credit, uncertainty about cotton prices and access to inputs tends to foster increased production of traditional sorghum varieties that do not need fertilizer rather than cereal intensification. The release of sorghum hybrids that perform well without inorganic fertilizers could stimulate renewed interest in sorghum production, but this will require solid efforts to dissemination information and make seeds available.

Since independence, it is fair to say that sorghum has been a bit of an orphan crop in terms of government support programs, with research, extension, credit, and subsidy programs focusing much more on cotton, rice, and more recently maize. Although agricultural strategy statements since 2000 have supported growth in sorghum productivity, investments in research, extension, market development, and infrastructure as well as budgets for input subsidies have favored the rice and maize sectors for a number of years, causing some to question how well actions are supporting strategies.

Overall, one sees continued tension between agricultural strategies addressing national food security and those addressing poverty reduction for small-scale farmers. A focus on increasing production of marketable maize and rice through input-intensive technologies contributes to growth in national food production, as these are the crops with the greatest yield potential. However, only 10 to 20% of farmers are marketing these crops, with the majority of farmers relying on less input intensive approaches to producing their own cereals, generally millet and sorghum. Reduction of this tension in a manner that responds well to both food security and poverty challenges continues to be a work in progress.

6.3. Sorghum Productivity Research and Dissemination Strategies

Breeding has been at the heart of Mali's sorghum research program. After many years of mediocre performance and a number of changes in breeding strategies, Mali's sorghum research programs have recently come of age, releasing 30 improved sorghum varieties (including many hybrids) since 2000. From 1990-2010, Mali ranked first of five West Africa nations in number of sorghum releases. In addition, researchers have embraced a more participatory approach to research that involves multi-locational testing with farmers at earlier stages of the research process, thereby creating varieties that better meet farmers' needs and enabling more rapid dissemination of results. Further support for dissemination of improved varieties has come from projects to develop farmer managed seed production/marketing services and from programs to expand the demand of industrial processors for improved varieties with good processing qualities. On the seed production/marketing front, financial sustainability of farmer managed activities has been a challenge due in large part to the very nature of sorghum, which has a low seeding rate (<10 kg/ha) and a low renewal rate (once every 3-4 years). On the industrial demand side, organizing farmers to provide a steady supply of desired varieties adequate to keep processing machines functioning on a regular basis has been a major challenge.

Research on agronomic practices of relevance to sorghum has gotten less attention than breeding, but work is ongoing to find more efficient and profitable fertilizer recommendations (micro-dosing currently looks promising), easier to implement soil and water conservation practices and better pest control techniques (particularly for *striga*). Much of the research on soil and water conservation was funded by the cotton sector and disseminated via cotton sector extension services. Extension of improved technologies through the more general government extension programs remains a challenge due to underfunding and relatively weak links between research and extension services. NGOs (e.g., SG2000) with access to international funding seem to be more active in disseminating research results for coarse grains than government extension services. There is very limited information about what farmers are actually doing in terms of sorghum input use and management practices and how yields vary by types of farmers and types of practices.

6.4. Adoption

Information on adoption is spotty with different data collection and estimation methods often resulting in different results. One of the most sought after adoption statistics is the percent of sorghum area planted to improved varieties. These estimates range from roughly 13% (nationally representative surveys) to 18% (estimate based on seed production data) to 30% (targeted sorghum adoption studies covering different geographic areas within Mali). Some of the targeted studies appear to have the best data (e.g., more precise definitions of improved varieties), but they often cover limited areas and cannot be used as national estimates. Better disaggregation of adoption data would also provide insights for future dissemination efforts to expand the use of improved seeds and practices. For example, do men and women adopt different varieties, use different agronomic practices, or obtain different yields? Are there differences in the approach to sorghum production between older and younger farmers? Are there geographic hot spots for adoption? How are these tendencies changing over time (e.g., more women and younger farmers producing sorghum now than in the past)? Despite the weaknesses of the adoption statistics, a synthesis of all the studies does suggest increased adoption over time, with more rapid growth in recent years. There is also growing evidence on the need to better integrate channels for the sale of improved varieties and traditional seed exchanges.

Information is also spotty on adoption of agronomic practices such as fertilizer use, intercropping, different types of land preparation, and soil and water conservation techniques capable of increasing cereal yields. While national statistics show Sikasso—a major sorghum producing region—using inorganic fertilizers on 57% of cultivated area, there is no disaggregation by crop. There is also no information on whether farmers adopting improved sorghum varieties are using recommended agronomic practices. Declining trends in sorghum yields for the recent past lead one to question the relatively high adoption rates reported in some studies and/or question the extent to which recommended agronomic practices are being used. Would it not be logical to think that if improved varieties are being used on 30% of the sorghum area, there would be some upward movement in yields? The Smale et al. (2014) census of farmers using improved varieties and supplementary data collection on farmers' practices may be able to partially address this issue, but it would also be useful to consider ways that the EAC could address the question through more systematic year-by-year data collection.

Information from studies reporting determinants of adoption and/or constraints to adoption offer no major breakthroughs in our understanding of the adoption process that can be generalized across a wide range of farmers. On the other hand, it appears that the more participatory approaches now being used for sorghum variety research will be getting this information to researchers and extension personnel sooner, with more likelihood that research can be fine-tuned to farmers' needs more rapidly while also taking into account site-specific factors and farmer characteristics that might influence adoption decisions.

6.5. Implications for Moving Forward

Although most reviews of Mali's sorghum variety improvement research have been favorable, it is clear that there has been an especially big surge in positive results during the recent past, with a range of sorghum hybrids having been released since 2008. The question remains as to whether appropriate strategies are in place to promote adoption of these latest varieties and adequate resources are in place to monitor adoption. This does not seem to be the case, particularly for the monitoring of adoption.

Formal extension services to promote sorghum are extremely weak, so alternative mechanisms for introducing the improved varieties to farmers who are outside the main IER/ICRISAT test areas will be needed. Can NGOs serve this purpose? What about agro-dealers? Adoption studies reviewed were so few and far between and so variable in results that we have no basis to recommend any particular strategy to promote adoption. However, testing and carefully monitoring the results of a variety of approaches to introduce different types of farmers to different types of improved sorghum technologies seems an appropriate next step given the recent breakthroughs in variety releases and evidence of adoption in ICRISAT test villages. In addition to monitoring the adoption of improved varieties, there needs to be more attention to monitoring the complementary agronomic practices that are used with the new varieties. To date, there is a dearth information on what agronomic practices farmers are using with improved varieties and how yields differ when practices differ, but research results suggest significant yield and income gains are possible with micro-dosing of fertilizers and a variety of soil and water conservation practices. Developing more systematic data collection for yield differentials obtained on farmers' fields and for adoption rates would seem a good investment. Six areas where systematic data collection is needed if researchers are to have more impact include:

- Levels and speed of adoption of technologies of interest;
- Feedback from farmers on reasons for adoption;
- Farmers' perceptions of constraints to adoption;
- Farm characteristics that are favorable to adoption (e.g., age, gender, location, asset base);
- Yield increases due to technology adoption; and
- Adoption impacts on income (or other indicators of well-being).

An issue that needs to be addressed in terms of promotion strategies is the extent to which new varieties will be targeted to farmers producing only for the market or also to farmers producing primarily for home consumption. Are some of the improved varieties better for marketing and others better for home consumption? Other aspects of the targeting issue include how strategies might differ by a farmer's access to inputs, average level of rainfall, access to markets and roads, access to land, etc. As noted in most of the sorghum research reports, sorghum varieties often perform best in very site-specific environments, adding another challenge for those designing dissemination programs.

In addition to the technical crop production issues that need to be addressed, the challenges of developing reliable seed supply and output markets remain. There is more optimism now than in the past about the development of seed production cooperatives and commercial firms, with ICRISAT reporting increased quantities of seed being produced, AGRA supporting a number of agro-dealers who are selling sorghum seed, and Smale et al. (2014) reporting increased monetization of seed exchanges. On the other hand, the potential for growth in sorghum demand is poorly understood, with most coarse grain analysts focusing on the growing demand for maize in animal feed and paying little attention to sorghum.

Finally, the most worrisome part of the picture is that to date there is little evidence in aggregate statistics that farmers are increasing either sorghum area or yields. These statistics do not seem consistent with what one would expect with estimates that roughly 30% of the sorghum area has been planted to improved varieties since the mid-1990s. The contrast between the large positive impact of government programs and policies on rice and maize production and its less perceptible impact on sorghum production illustrates the need to foster synergies to elicit strong agricultural productivity growth in the sorghum sector. Attention must be directed simultaneously at technology development, strengthening and reform of institutions governing production and marketing, and macro-economic policy reform if sorghum is to realize its full potential to contribute to Mali's food security and poverty reduction goals. The marketing reforms in the *Office du Niger* were effective largely because farmers in the zone had the technical capacity to respond quickly by intensifying production and the GOM was investing in both irrigation and roads (Aw and Diemer 2005; Bonneval, Kuper, and Tonneau 2002). Similarly, extension services and input supply provided by the CMDT in the cotton zone encouraged the surge in maize production. Now that we have significant breakthroughs in sorghum variety improvements, and some signs of farmer interest in the new varieties, it is time to get the rest of the system up and running in a manner that shows some lessons have been learned from the rice and maize sectors that can be applied to the sorghum sector.

APPENDICES

Appendix 1. Characterization of the Main Agro-Ecologies Where Sorghum Is Grown in Mali

Agro-ecology and rainfall zone	Predominant soil conditions	Predominant uses of sorghum	Main biotic constraints of sorghum
Saharanlian (100-6,250mm)	NA	NA	NA
Western Sahel (Northern parts of Kayes and Koulikoro regions, 300-600mm)	Sandy soils with low lying, clayey areas	In low lying areas even later maturing, guinea type sorghums for food, on sand dunes durra type sorghum largely as animal feed	Blister beetles, which mostly attack millet, have led to increased cultivation of sorghum; some opportunities for intensification exist.
Central Sahel zone (Northern parts of Segou region 400-700mm)	Highly degraded soils, mostly sandy, with loamy areas near the large river systems	Early maturing guinea type sorghums	Striga is the main constraint; head bugs can occur and can lead to grain mold in case of late rains.
Northern Sahel (Mopti region, 300-500mm)	Mostly sandy soils, with some loamy areas	Very large diversity of races, grown in spaces with heavy soils, or water stagnation	Striga is the main constraint. Birds can be serious, especially if sorghum grain matures very early, or very late
Decrue zone (recession farming in areas flooded by the rivers)	Heavier soils with good water holding capacity	Decrue sorghums belong to the durra race, are directly sown or transplanted as flood waters recede	Birds, and stem borers are the main constraints
Sudan savannah (700-1,000 mm)	Heavier soils, generally degraded, some with tendency for water stagnation	Sorghum is the dominant cereal crop, photoperiod sensitive types with Guinea-type grain for human consumption. Also a high potential zone for sorghum hybrids.	Striga, headbugs, grain molds, and leaf diseases
Northern Guinea savannah (1,000–1,300 mm)	Heavier soils, tendency for water stagnation	Frequently rice-type sorghum with very hard small grains	Birds, various insects and leaf diseases, as well as smuts

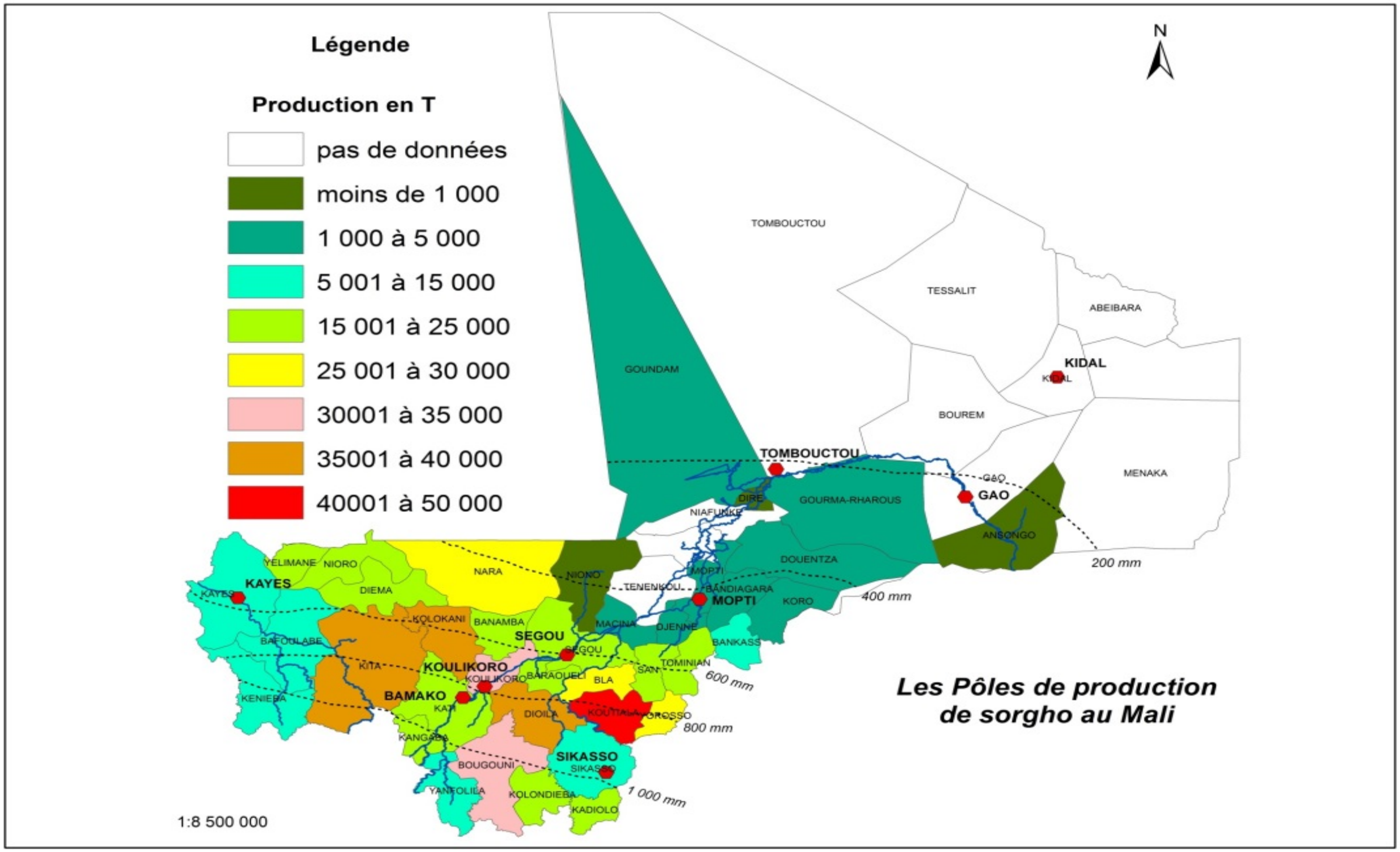
Source: L. Diakité et al. 2013a.

Appendix 2. Average Annual Cereal Production by Administrative *Cercle*: 1990-2005

Cercles	Millet	Cercles	Sorghum	*Cercles*	Maize	*Cercles*	Rice	*Cercles*	Fonio	*Cercles*	Wheat
Ségou	1,375,835	Koutiala	754,826	Kadiolo	912,058	Niono	3,869,404	Tominian	75,967	Diré	69,122
Koro	1,306,362	Kolokani	613,201	Yanfolila	792,516	Macina	1,195,160	Kéniéba	43,447		
Bankass	896,347	Kita	612,274	Sikasso	461,647	Mopti	621,069	Kolondiéba	42,551		
Baraouéli	886,468	Dioïla	591,253	Kolondiéba	457,385	Djenné	492,879	Bankass	29,549		
Macina	872,366	Koulikoro	482,383	Bougouni	412,055	Ségou	344,756	San	27,571		
Bla	770,417	Bougouni	481,549	Dioïla	409,693	Diré	314,092	Yanfolila	20,232		
Koutiala	725,580	Yorosso	465,629	Koutiala	361,766	Kangaba	284,495	Ségou	19,981		
Banamba	711,378	Nara	416,700	Kangaba	282,922	Yanfolila	265,259	Kadiolo	17,620		
Youwarou	496,589	Bla	411,879	Bla	197,777	Ténenkou	264,244	Bougouni	16,411		
Kadiolo	101,087	Kadiolo	357,560	Kati	172,102	Kadiolo	252,396	Bafoulabé	14,639		

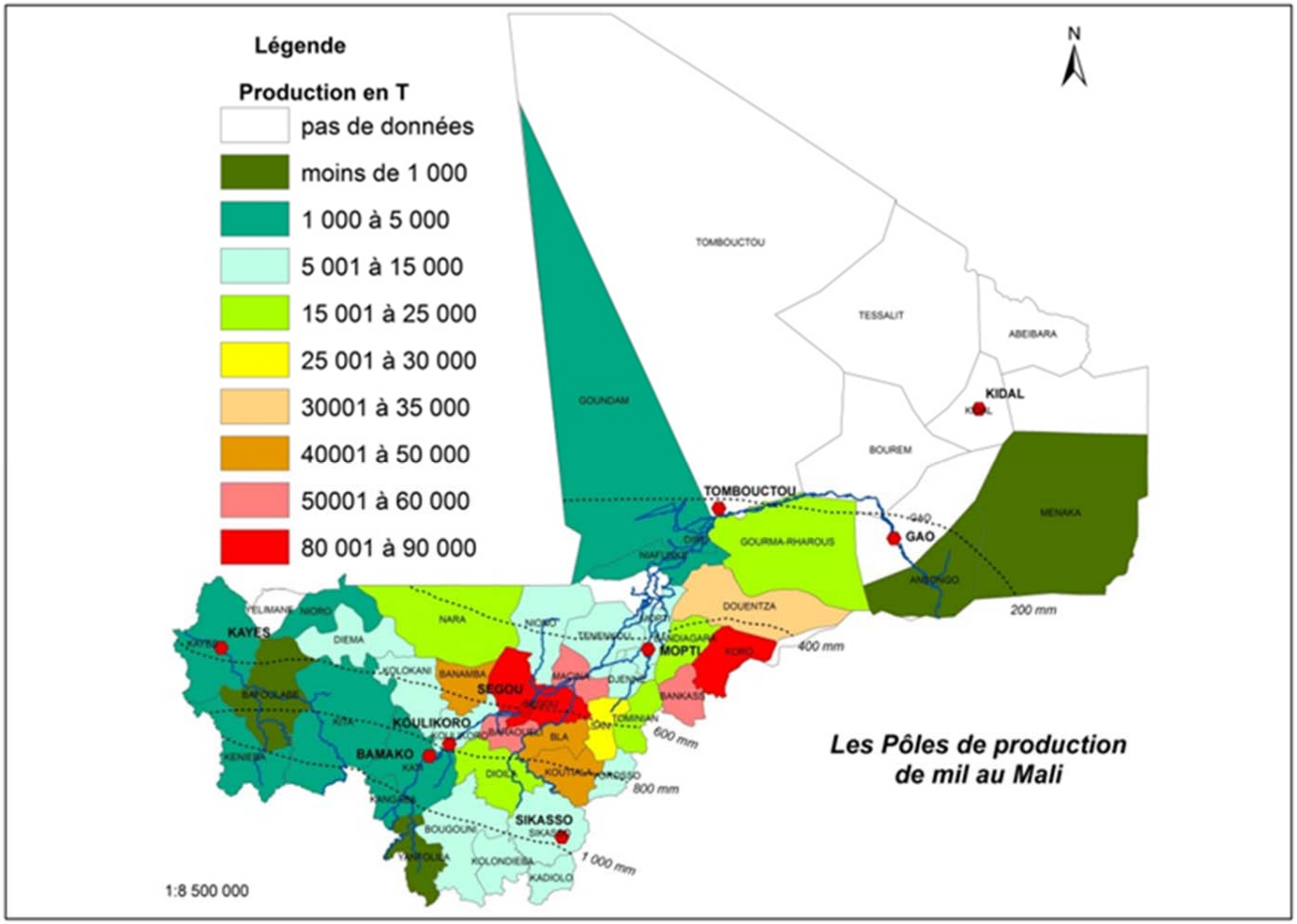
Note: *Cercles* are listed in descending order of production, which is reported in metric tons.
Source: FAO/Country statistics and CPS/SDR data analyzed by Teme, Diakité, and Touré 2013.

Appendix 3. Map of Sorghum Production Basins in Mali: *Cercle* Level



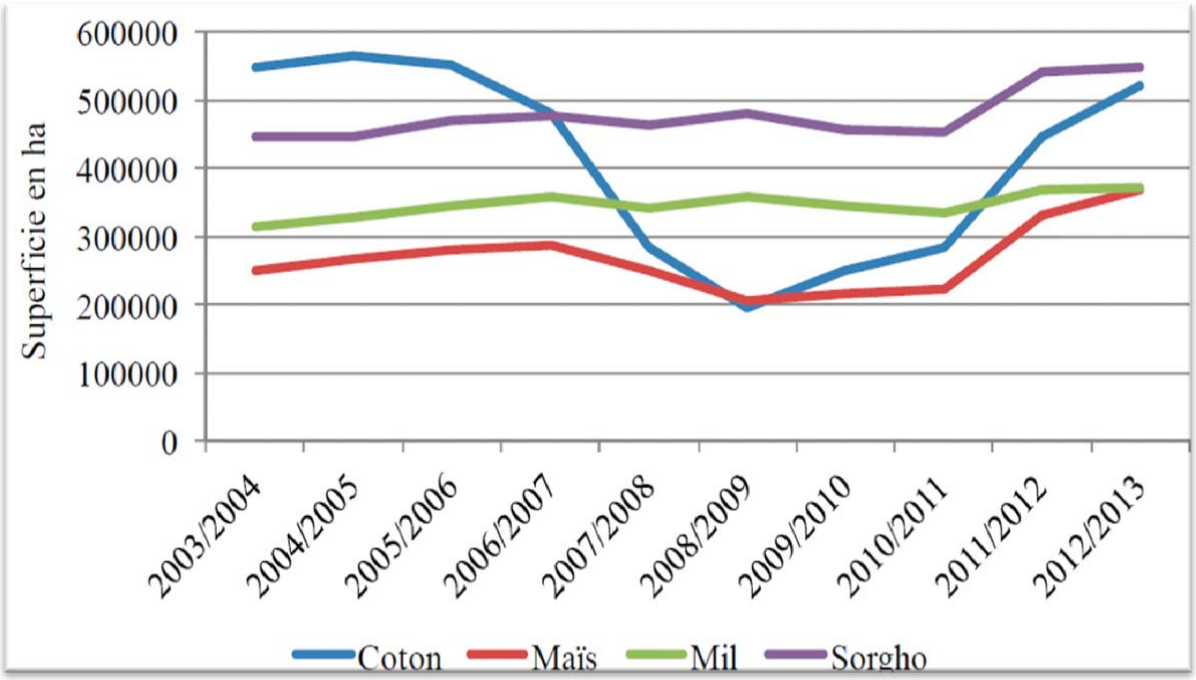
Source: Yiriwa Consulting 2013.

Appendix 4. Map of Millet Production Basins in Mali: *Cercle* Level



Source: Yiriwa Consulting 2013.

Appendix 5. Cotton Zone Area Trends for Cotton, Maize, Millet, and Sorghum: 2003-2012



Source: Sissoko et al. 2013.

Appendix 6. Improved Varieties of Sorghum and Sorghum Hybrids Disseminated in Mali

Name	Type V=OPV H=Hybrid, R=Restorer	Adaptation Zone	Rainfall isohyet (mm)	Photo-period Sensitivity Class*	Plant Height m	Release Year
SANGATIGUI	V	Sahelian	500-600	L	3	1992
SEGUIFA	V	Sahelian	500-600	L	2	1995
JAKUMBE (CSM 63E)	V, R	Sahelian	500-800	L	3	1984
WASSA	V	Sahelian	500-600	M	3.5	2007
SOUMBA	V	Sudanian	600-800	L	2.4	1999
GRINKAN	V, R	Sudanian	700-900	L	2	2002
TIANDOUGOU	V,R	Sudanian	800-1,000	L	1.8	2002
DARRELLKEN	V	Sudanian	700-900	L	3.5	2002
N'TENIMISSA	V	Sudanian	800-1,000	L	3.5	1995
JIGISEME (CSM 338)	V, R	Sudanian	800-1,000	M	3.7	1984
NIATCHITIAMA	V	Sudanian	800-1,000	M	2	2002
SEGUETANA-CZ	V	Sudanian	600-900	M	3.5	1989
TIEBLE (CSM 335)	V	Sudanian	800-1,000	M	3.6	1999
N'GOLOFING (CSM 66660)	V	Sudanian	700-900	M	4	2002
SOUMBA (CIRAD 406)	V	Sudanian	600-900	M	2.5	2002
MARAKANIO CGM 19-1-1	V	Sudanian	700-900	M	2.5	2002
SAKOYKABA	V	Sudanian	800-1,000	M	4	2002
TOROBA	V	Sudanian	700-1,000	M	4	2005
LATA	V,R	Sudanian	800-1,000	M	3	2009
DIEMA	V,R	Sudanian	800-1,100	L	4	2012
BOBOJE	V	Sudanian Savannah	800-1,200	H	3.8	2005
ZARRA	V	Sudanian	800-1,000	M	4	2002
TIEMARIFING	V	North Guinean	1,000-1,200	H	4.5	1984

Appendix Table 6, Contd.

Name	Type V=OPV H=Hybrid, R=Restorer	Adaptation Zone	Rainfall isohyet (mm)	Photo-period Sensitivity Class*	Plant Height m	Release Year
DOUAJE	V	North Guinean	800-1,200	H	3.5	2010
NIELENI	H	Sudanian	700-900	L	3	2011
FADDA	H	Sudanian	800-1,000	M	3	2008
SEWA	H	Sudanian	800-1,000	M	2.5	2008
SIGUI-KOUMBE	H	Sudanian	800-1,000	M	2.5	2008
HOUDÔ	H	Sudanian	800-1,000	M	2	2012
OMBA	H	Sudanian	800-1,000	M	4	2012
PABLO	H	Sudanian	700-1,000	M	4	2012
YAMASSA	H	Sudanian	800-1,000	M	5	2012
CAUFA	H	Sudanian	800-1,000	M	4	2012
NIAKAFA	H	Sudanian	800-1,000	M	4	2012
GRINKAN YEREWOLO	H	Sudanian	800-1,000	M	2	2010

Source: Personal communication Eva Weltzien-Rattunde, ICRISAT.

Notes: *Class L=Least, M=Moderate, H=High. There is some uncertainty about Nieleni, but we have retained it in the table to signal the need to clarify what variety this name frequently used by farmers really represents.

Appendix 7. Effects of Different Levels of Fertilizer on Sorghum Yields

A. Improve Sorghum Variety in a Zone of 600–800 mm of Rainfall

		Control	Micro-dose	Standard fertilizer recommendation
Fertilizer (kg/ha)		0	33 kg/ha of DAP	100 kg/ha of DAP and 50 kg/ha of urea
Yield (kg/ha)	2009	627 c	938 a	851 b
	2010	653 b	1,258 a	1,377 a
	2011	880 b	1,227 a	1,200 a
Avg yield		720	1,141	1,143
Productivity index	2009		15.19	2.57
	2010		29.54	8.32
	2011		16.94	3.68
Avg index			20.56	4.86

Source : Adapted from Sogodogo et al. 2013.

Notes: N=30 en 2009, 218 en 2010, et 7 en 2011. The productivity index is the amount of additional yield attributed to the fertilizer divided by the kilograms of nutrient content in the fertilizer application. The letters a, b, and c indicate results that are statistically different from each other in a given year: those with similar letters are not statistically different.

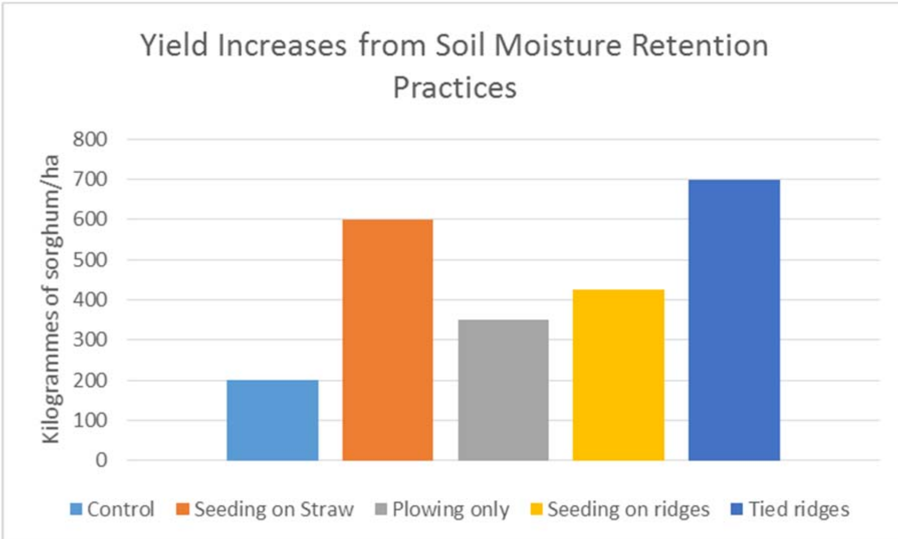
B. Improved Sorghum Variety in a Zone of 800-1000 mm of Rainfall

		Control	Micro-dose	Standard fertilizer recommendation
Fertilizer (kg/ha)		0	53 kg/ha of CC*	100 kg/ha of DAP and 50 kg/ha of urea
Yield (kg/ha)	2009	707 b	1,184 a	1,019 a
	2010	647 c	1,152 a	1,232 a
	2011	1,289 c	1,850 a	1,746 a
Avg yield		881	1,395	1,332
Productivity index	2009		14.06	3.59
	2010		14.89	6.72
	2011		16.54	5.25
Avg index			15.16	5.19

Source: Adapted from Sogodogo et al. 2013.

Notes: N= 7 en 2009, 206 en 2010 et 29 en 2011. * We believe that CC is an abbreviation for *complex céréale*, i.e., an NPK product such as 15/15/15, but the original document does not specify.

Appendix 8. Yield Impacts of Soil Moisture Retention Practices



Source: Adapted from Figure 5a in Coulibaly et al. 2014b.
Note: Tied ridges is referred to as *billons à sillons cloisonnés* in French.

Appendix 9. Mechanical Seeding and Micro-dose Effects on Sorghum: Sotuba 2013

Traitement	Poquets Emergés/ha 3jas	Diam.Tige 30jas mm	Poquet récoltés ha	Grain kg /ha	Accr. %
T1- Semis mécanique, semences non trempées et sans engrais	14,020	6	22,940	783	-
T2- Semis mécanique, (semences non trempées + micro-dose 0.2g .poquet)	13,660	9	21,470	966	23
T3- Semis mécanique, (semences trempées + micro-dose 0.2g .poquet)	12,140	9	19,410	1,566	62
T4- Semis mécanique semences trempées, semence et micro-dose d'engrais dans différents sillons	14,640	9	25,290	**2,199**	
SED	1,353	2.3	3,128	156	
P>F	0.289	0.09	0.35	0.004	
CV (%)	15	27	29	41	

Source: Coulibaly et al. 2014b.

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Appendix 10. Hectares Planted to Improved Seed by Region and Gender of Household Head: 2004

Tableau 73 : Répartition régionale des exploitations agricoles ayant accès aux semences améliorées selon le sexe du chef d'exploitation

Région	Masculin				Féminin				Total		
	Nombre exploitations	Exploitation utilisant les semences améliorées		Taux d'utilisation des semences améliorées	Nombre exploitations	Exploitation utilisant les semences améliorées		Taux d'utilisation des semences améliorées	Nombre exploitations	Exploitation utilisant les semences améliorées	
		Effectif	%			Effectif	%			Effectif	%
Kayes	92 433	8 186	5,0	3,4	4 064	140	8,5	8,6	3,4	8,6	5,0
Koulikoro	119 694	39 362	24,0	25,1	2 616	656	39,7	32,7	25,1	32,7	24,2
Sikasso	96 580	80 420	49,1	44,6	975	435	26,3	82,9	44,6	82,9	48,9
Ségou	115 045	28 046	17,1	10,8	2 109	228	13,8	24,1	10,8	24,1	17,1
Mopti	150 409	4 977	3,0	1,3	6 378	84	5,1	3,2	1,3	3,2	3,1
Tombouctou	48 992	999	0,6	0,0	3 024	-	-	1,9	0	1,9	0,6
Gao	42 266	730	0,4	0,0	2 445	-	-	1,6	0	1,6	0,4
Bamako	6 791	1 083	0,7	14,9	738	110	6,7	15,8	14,9	15,8	0,7
Total	**672 211**	**163 804**	**100,0**	**7,4**	**22 349**	**1 655**	**100**	**23,8**	7,4	23,8	**100,0**

Source: République du Mali 2007.

Appendix 11. Percent of Sorghum Area Cultivated by Improved Varieties (by Country and Variety): 2010

	Mali		**Niger**			Senegal	
Grinkan	4.26%	MM (Mota Maradi)	3.63%			F2-20	12.03%
Tiandougou coura	4.36%	Sepon 82	4.95%			CE145-66	9.30%
Seguifa	6.97%	IRAT204	2.74%			CE151	10.57%
Tiandougou	0.12%	90SN7	0.14%			CE181	9.30%
Niatitiama	1.14%	SSD35	2.91%			nganda	9.54%
Darrelken	1.48%	MAR	0.02%			Faourou	9.51%
Djiguisene	1.46%	NAD-1	0.45%			Nguinthe	1.85%
Sewa (hybrode)	4.02%	S35	0.13%			Darou	1.85%
Grinkan (hybride)	2.01%	90SN1	0.01%				
Jacunbe	2.68%	SRN39	0.07%				
Wassa	1.11%						
ICSV401	0.65%						
97-SB-F5DT-63	0.02%						
Kalaban	0.68%						
98-SB-F2-78	0.11%						
IS15401	0.00%						
Marakanio	0.68%						
97-SBF5DT-150	0.79%						
	21.10%		5.46%				0
	32.55%		**15.05%**				**41.19%**

Source: Ndjeunga et al. 2012 (page 29).

Appendix 12. Extract from Methods Section of Ndjeunga et al. 2012 (page 12)

Document the perceived adoption of new varieties in 2009.

Data on adoption of released varieties was collected using focus and individual group interviews with key partners such as breeders, agronomists, technicians, managers of seed companies, farmers' organizations seed producers etc. After the first meeting in Niger with stakeholders attempting to collect data on adoption, it was clearly evident that breeders, extension agents and representative of seed companies had difficulties estimating the potential area occupied by released varieties nationwide. The estimates were often largely above realism. However, it was easy for scientists to point to individual locations at districts or regional levels where varieties could be found and to provide guess-estimates of the percent adoption in those specific locations.

Based on these facts, we carried out individual interviews with partners including scientists, research technicians, and extension agents in the selected countries. Partners were first asked to elicit the varieties that they know have been adopted or have heard of- from trusted sources that those varieties are being planted by farmers. Then partners were asked to rank the varieties the order of decreasing importance in terms of area cultivated. Partners were then given each a map of locations at the district/regional level in the country and were asked to locate districts where they have effectively seen the varieties or where they have heard from trusted sources that the varieties are in the district. Then, for each district and variety, partners were asked to provide the percent area occupied by the variety (less than 1%=very low, between 1% and 5%=low, between 5 and 10% =average and 10% and more).

At this stage, we gathered data on guess-estimates of adoption at the district level for each variety. This data set was combined with country/national statistics on sorghum, pearl millet or 12 groundnut areas at the district level in order to derive aggregate area cultivated with the variety at national level. This area was divided by the total area planted with the crop to provide the guess-estimates of adoption at the national level. In the case where the district level information was not available as in Mali, the regional estimates of areas were used and weighted averages of areas cultivated with the crop were computed at the district level1. In the case of Nigeria, we could not carry out the interviews with partners involved with sorghum and pearl millet. This is also the case for sorghum in Burkina Faso. Finally, the guess-estimates obtained from these computations were validated by mails by the scientists in countries and re-validated during an expert meeting held in Niamey, Niger from 6 to 7 August 2012.

Appendix 13. Estimates of Adoption Rates for Improved Varieties of Sorghum: 1990-1995

Table 10. Adoption rates (as a percentage of the total rainfed sorghum area)of improved sorghum varieties in Mali, 1990-1995.

	Mopti region		Ségou region		Koulikoro region		All three regions	
Year	Generation 1	Generation 2	Generation 1	Generation 2	Generation 1	Generation 2	Generation 1	Generation 2
1990	14	0	14	0	16	4	15	4
1991	16	0	13	2	18	5	16	4
1992	19	0	13	2	18	5	17	4
1993	19	0	15	3	19	5	18	4
1994	20	0	18	3	19	7	19	6
1995	23	0	23	6	21	9	22	8
Varieties	CSM 63-E		Tièmarifing	CE 151	Tièmarifing	CE 151	CSM 63-E	CE 151
	CSM 219		CSM 219		Séguètana	ICSV 1063BF	CSM 219	ICSV 1063BF
	CSM 388		CSM 388		CSM 388	ICSV 1079BF	CSM 388	ICSV 1079BF
							Tiémarifing	
							Séguètana	

Source: Authors' computations are based on farm-level survey results.

Source: Reproduced from Yapi et al. 2000.

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