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An Overview and Economic Assessment of Sorghum Improvement in Mali

by

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EXECUTIVE SUMMARY

Sorghum is one of the world's most important cereals in terms of total production. Grown largely as livestock feed in the US, sorghum is a primary food staple and source of cash for smallholder farming families in the West African savannah. The dominant type of sorghum produced in this region is the Guinea race, which has unique traits that enable it to adapt well to irregular, uncertain rainfall conditions and resist endemic pests.

Sorghum occupies a central role in the agricultural economy of Mali, although less so than it did at independence in terms of total volume and value produced since rice and maize have gained in terms of cropped area and diet with urbanization, irrigation schemes, and the cotton commercialization. Maize is grown primarily in rotation with cotton, where growing conditions are favorable, and producers benefit from support services that provide fertilizer and high-yielding seed.

More recently, the global food-price crisis in 2008 and ensuing political and economic insecurity have contributed to vacillation in sorghum area planted. A constraint to sorghum commercialization in Mali (and thus to incentives for farmers to adopt certified seed), is that while there is a strong demand in local markets, there is no organized marketing or trade association because sorghum continues to be viewed as a subsistence crop. Moreover, given the cultural and historical importance of sorghum in this region, farmers have not been accustomed to purchasing certified seed and sourced seed most frequently from their own harvests or other farmers. The formal seed system for sorghum seed was state-managed and its *reach* in rural areas limited to extension services.

Sorghum remains crucial in the rural economy and diets of rural households (second in consumption to millet), and is grown in every agroecology of Mali except the driest, Sahelian zone at the border of the Sahara desert. Raising sorghum productivity has been a major policy goal since the Sahelian droughts of the 1970s-1980s, when national and international research systems accelerated efforts to enhance sorghum productivity, including the introduction of exotic germplasm. Since then, studies show that adoption rates for improved sorghum seed have gradually risen.

In this study, we review contextual information and past adoption studies, updating an earlier in-depth analysis by Yapi et al. (2000). The study by Yapi et al. (2000), which was also commissioned by ICRISAT, led to directional changes in Mali's sorghum improvement program. Germplasm developed today in Mali encompasses a range of types that combine Guinea-race and exotic materials; the first Guinea-race sorghum hybrids were introduced in 2009 for testing by farmers.

Few studies have systematically assessed the adoption of improved sorghum varieties on a large geographical scale in Mali. As part of this study, we conducted a census of sorghum varieties grown in 60 villages in the high-potential, sorghum-producing zone of the Sudan Savannah, where the national and international breeding programs have introduced materials. We then analyzed the returns to research investment in an ex post, economic surplus framework.

About four-fifths of all farmers in the 58 villages grew sorghum. Enumerators asked farmers to identify all sorghum varieties grown over the previous five years. Farmers named 136 varieties of sorghum that could be identified by trait and type by technicians and breeders. Within this time frame, adoption rates varied considerable across villages, from nearly zero to

over 80% of farmers. During these years, the percentage of area planted to improved varieties, especially sorghum hybrids, increased. All improved varieties and hybrids represented 28% of sorghum area in 2013. It is important to recognize that many of these are new materials that replaced older improved materials, and some of those classified by farmers as local, and given local names, could be advanced generations of improved germplasm.

The changing role of women in sorghum production has emerged in recent studies and is a subject of upcoming research. Use rates for improved varieties and hybrids do not differ meaningfully between men and women plot managers. 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. Adoption rates are clustered by farm family, suggesting that intra-household decision-making is a key consideration in technology uptake.

There are also indications of increasing cash purchase of seed—though modes of acquisition continue to have a socially-based, community locus. It is noteworthy that organized visits (by outsiders, such as ICRISAT scientists) were not important routes of acquisition.

Assuming only a 21% yield advantage and a ceiling adoption rate of 33% of national sorghum area, the rate of return to investment in sorghum improvement in Mali since 1997 is estimated at 25%, with six dollars earned for every dollar invested. Each year, on average, 20,000 persons are estimated to have crossed the $1 poverty line as a result of higher sorghum productivity. Increasing the yield advantage to 31%, with no change in other parameters, generates an internal rate of return of nearly 60% and a benefit-cost ratio of 63:1. Across a broad range of management conditions on farmers' fields, the estimated average yield advantage associated with newly released sorghum hybrids is 30%. These estimates compare favorably with the more conservative estimates generated in other global studies, and should be understood as a lower bound on our overall estimates of gains from Mali's sorghum improvement program.

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ACRONYMS

ACoD	*Association Conseil pour le Développement*
AMEDD	*Association Malien pour d'Eveil au Développment Durable*
AOPP	*Association des Organisations Professionelles des Paysannes*
B/C	benefit–cost ratio
CGIAR	Consultative Group on International Agricultural Research
CIRAD	*Centre de Coopération Internationale de Recherche Agronomique pour le Dévelopment* / Agricultural Research Centre for International Development
CPS-SDR	*Cellule de Planification Statististique du Secteur du Développement Rural*
EAFs	family farm enterprises/*exploitations agricoles familiales*
ECOFIL/ER	*Economie de la Filière, Institut d'Economie Rural*
FAO	Food and Agricultural Organization of the United Nations
FAOSTAT	Food and Agricultural Organization Online Statistical Database
GISAIA	Guiding Investments in Sustainable Agriculture in Africa
ICRASAT	International Crops Research Institute of the Semi-Arid Tropics
IER	Rural Economy Institute/*Institut d'Economie Rurale*
IFPRI	International Food Policy Research Institute
IITA	International Institute of Tropical Agriculture
ILRI	International Livestock Research Institute
INSAH	*Institut du Sahel*
IRAT	*Institut de Recherche Agronomique Tropicale*
IRD	*Institut de Recherche pour le Développement*
IRR	internal rate of return
kcal	kilo calorie
kg/ha	kilograms/hectare
MM	millimeter
NGO	Non-governmental Organization
NPV	net present value
OHVN	*Office pour la Haute Vallée du Niger*
OMA	*Observatoire du Marché Agricole*
OPV	Open Pollinated Variety
RGPH	*Recensement Général de la Population et de l'Habitat*
ROCARS	*Reseau Ouest et Centre Africaine de Recherche sur le Sorgho/*West-African Sorghum Research Network
SSN	*Service Semencier National/*National Seed Service
ULPC	*Union Local des Producteurs des Cereales*
UNDP	United Nations Development Program
US	United States
USAID	United States Agency for International Development
USD$	US Dollars
WARDA	West Africa Rice Development Association

1. INTRODUCTION

Archaeological evidence indicates that economies based on sorghum, pearl millet, cattle and goats were established along the southern fringe of the Sahara 3,000 to 5,000 years ago (Smith 1998). Today, south of the Sahara, five major morphological forms or *races* of sorghum are recognized (Olsen 2012). These include caudatum sorghum (originating in eastern Africa), durra (found in the Horn of Africa and other arid regions), kafir (subequatorial eastern Africa), and bicolor (broadly distributed). The fifth form is the Guinea race, which dominates the West African savannah, where most of the continent's sorghum is now produced. Guinea-race sorghum possesses several traits that confer unique adaptation to this region. Photo-period sensitivity enables the plant to adjust to the length of the growing seasons, which is important for farmers when rainfall is uncertain; plants of Guinea-race sorghum also have lax panicle and open glumes, which reduce grain damage from insects and mold (see Rattunde et al. 2013 for related references, including Barro-Kondombo et al. 2008; Hausmann et al. 2012).

Sorghum is one of the world's five most important cereals in terms of total production, following rice, wheat, maize, and barley. The largest single country producer is the US, where sorghum is grown primarily for livestock feed. Yet, some of the world's poorest people depend on sorghum as both a primary food staple and ready source of cash. An example is Mali, which ranked 176 out of 187 countries on the Human Development Index (UNDP 2013). Nearly 80 % of Malians farm (Recensement General de l'Agriculture 2006), and the vast majority cultivate under dryland conditions. The most economically important drylands cereals are millet and sorghum. Key food security crops, sorghum, and millet are destined primarily for consumption by the farmers who produce them in various forms, including a stiff porridge called *tô*, gruel, couscous, floury and fermented beverages, and fried dough.

Given its central role in the agricultural economy of Mali, raising sorghum productivity has been a major policy goal. During the Sahelian droughts of the 1970s-1980s, national and international research systems accelerated efforts to enhance sorghum yields productivity, including the introduction of exotic germplasm. Estimates of adoption rates for improved sorghum differ markedly by source, measurement approach, and scale of analysis, although there is little doubt that these continue to rise. Matlon's (1990) estimate for use of improved seed in the West African Sahel was a mere 5%. The 2006 Agricultural Census indicated that nearly 10% of area in drylands cereals was planted to improved seed, compared to over 89% of the area in industrial crops (in which rice was included). Using the amounts of certified (R2) seed produced as an indicator, and assuming replacement in the fourth year of use, Diakité et al. (2008) estimated that the area planted to improved sorghum seed had doubled from about 8% in 1996 to 16% in 2006. Diakité's (2009) analysis of farm surveys conducted in the areas around San and Sikasso showed that 20% of farmers grew improved sorghum seed.

In an assessment commissioned by ICRISAT, Yapi et al.'s (2000) found that nearly 30% if sorghum area was planted to improved seed in major sorghum-producing zones of Segou, Mopti, and Koulikoro. Yapi et al. (2000) differentiated between two breeding approaches pursued by the national sorghum improvement program: (1) selection and "purification" of superior landraces, and (2) crosses with exotic germplasm and pedigree selection. They found that despite the greater farm-level impacts of exotic germplasm in terms of yield advantages, farmers preferred the superior landraces. The net present value of benefits (NPV) associated with varieties bred from exotic germplasm was greater, but the internal rate of return to research investment (IRR) for improved landraces was higher because of the shorter time lag to adoption. Overall, Yapi et al. (2000) found an overall rate of return to investment of 69%.

Yapi et al.'s findings laid part of the foundation for directional changes in Mali's sorghum improvement program. Subsequent research also documented that although introduced cultivars had yield potential, their grain quality was not well appreciated. Improved sorghum cultivars from this period lacked resistance to insects and mold, jeopardizing the food security of farm households. Overall, achieving more than marginal yield changes has been difficult without hybrid vigor. The tremendous variation in climate, soils, and farming systems means that the degree of plant stress is not only high, but also highly variable within and among fields in close proximity. Farmers need observation over seasons and across plots to recognize whether or not a new variety has predictable advantages. This is a strong argument for farmer-managed trials early in the research and development process.

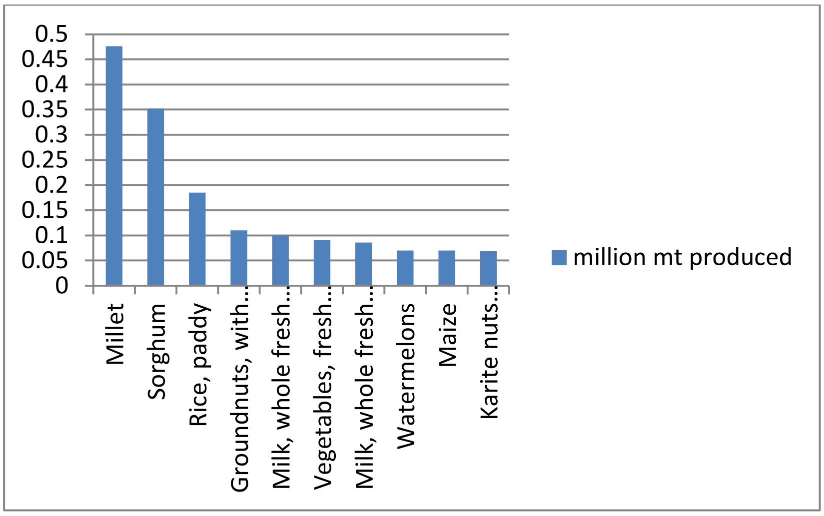
The objective of the report is to update the analysis conducted by Yapi et al. (2000). Since that study, in addition to the continued release of improved varieties bred from a combination of Guinea-race and exotic germplasm, Mali's sorghum breeding program has embraced two new directions. The first is a participatory approach to sorghum improvement, based on a network of multi-locational, farmer-managed field trials. The second is the development of the first Guinea-race, photoperiod-sensitive sorghum hybrids. Our analysis consists of two components: (1) an assessment of the economic impact of major varieties of improved sorghum released since the study by Yapi et al. (2000), including recently released sorghum hybrids, based on an economic surplus model; and (2) a census of sorghum variety and hybrid seed use, covering 60 villages where farmers have tested materials.

The following two sections of this report provide contextual information. In Section 2, we use secondary data sources to summarize the role of sorghum in the Malian economy. A brief history of the sorghum improvement program and a synopsis of relevant findings from previous studies about sorghum seed use are presented in Section 3. We summarize the methodology for our analysis in Section 4. Findings are presented in Section 5, followed by conclusions (Section 6).

2. SORGHUM IN THE MALIAN ECONOMY

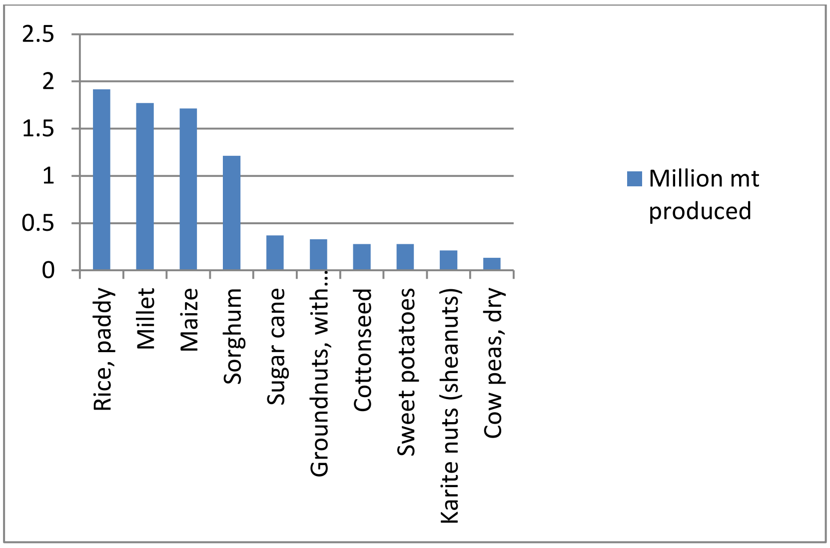
Historically, millet and sorghum were of much greater importance in Mali than they are today in terms of volume and value produced. The top ten agricultural products in 1961 and 2012 are shown in Figures 1 and 2, respectively. The rank of the top cereals is the same whether computed according to production or when compared in terms of value in each year. The major difference between the two years is that in 2012, among cereals, rice now assumes the highest rank in terms of either production or value of production, and maize ranks third, above sorghum (FAOSTAT last accessed December 15, 2013).

Figure 1. Top Ten Agricultural Products in Mali (Million MT Produced) 1961



Source: FAOSTAT 2013.

Figure 2. Top Ten Agricultural Products in Mali (Million MT Produced) 2012

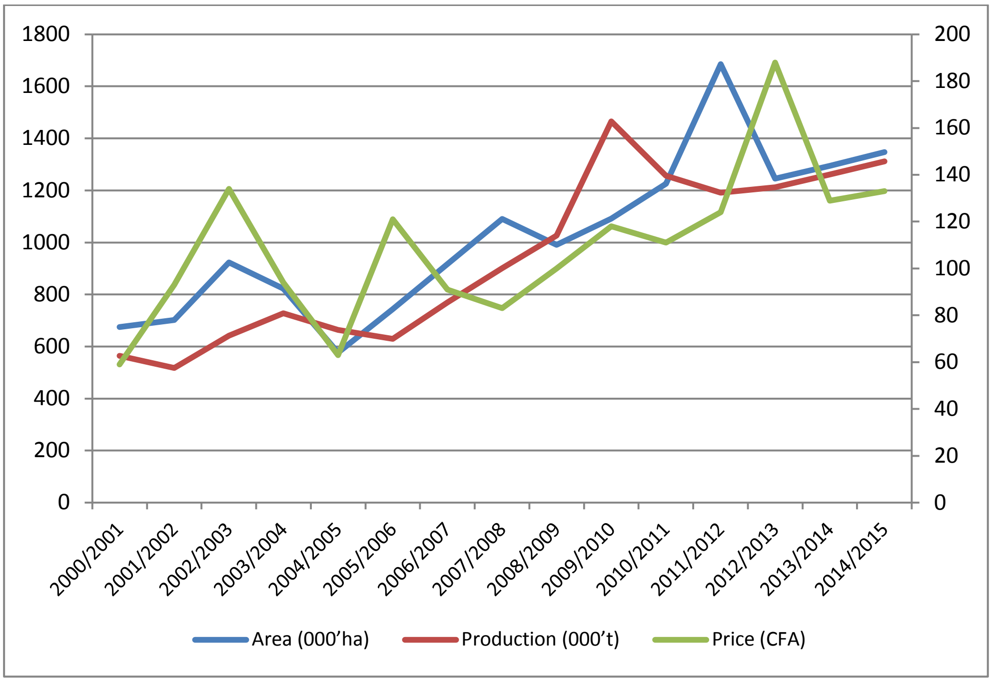


Source: FAOSTAT 2013.

Yields reported by the United Nations Food and Agricultural Organization Online Statistical Database (FAOSTAT) for 2009 through 2012 seasons are particularly erratic. Excluding 2009-2012, the average growth rate in sorghum yields from 1961 to 2012 is 0.35%; including the series from 1961 through 2012, the average growth rate is considerably higher (0.49%). FAOSTAT data are based on statistics provided by the *Cellule de Planification Statistique* (CPS). Examining the CPS data more closely for the period beginning in 2000, we see that the variability in area, production, and price is pronounced from 2007 to 2014 (Figure 3). A combination of external and internal shocks contributed to this variability. In 2007, during the global food price crisis, the government of Mali decided to subsidize seed and fertilizer in some crops in order to stimulate production and reduce food prices in 2008. Prices declined from 2009 to 2011. A dry spell occurred during the 2011/2012 season. Prices rose. At the end of the year, Mali experienced a military coup which favored invasion by Jihadists, affecting 2/3 of the country. Many farmers left their villages and migrated south. Consequently, production has declined and prices increased two folds (Kimenyi et al. 2014). With the liberation of the country from Jihadists in 2013, sorghum prices again decreased.

Trends for maize and rice are much more impressive overall than for sorghum. For purposes of comparison, average national yields in Mali were 1.0 mt/ha for sorghum, as compared to 0.8 for millet, 0.7 for fonio, and about 2.5 mt/ha for rice and maize over the 3-year period 2009-2011(Cellule de Planification et du Statistique 2014). Rice and maize (via its production with cotton) have benefited from well-organized, subsidized value chains that ensure a steady supply of improved seed and fertilizer, and are grown in areas with better moisture. Maize occupies an increasingly important role in consumption and in the growth of cereal production, and is grown primarily in rotation with cotton, where growing conditions are favorable and producers benefit from support services that provide fertilizer and high-yielding seed. Rice is a major cereal crop produced under irrigated and recession agriculture; minor areas are also planted in fonio and wheat.

Figure 3. Sorghum Cultivated Area, Production, and Price in Mali from 2000 to 2014

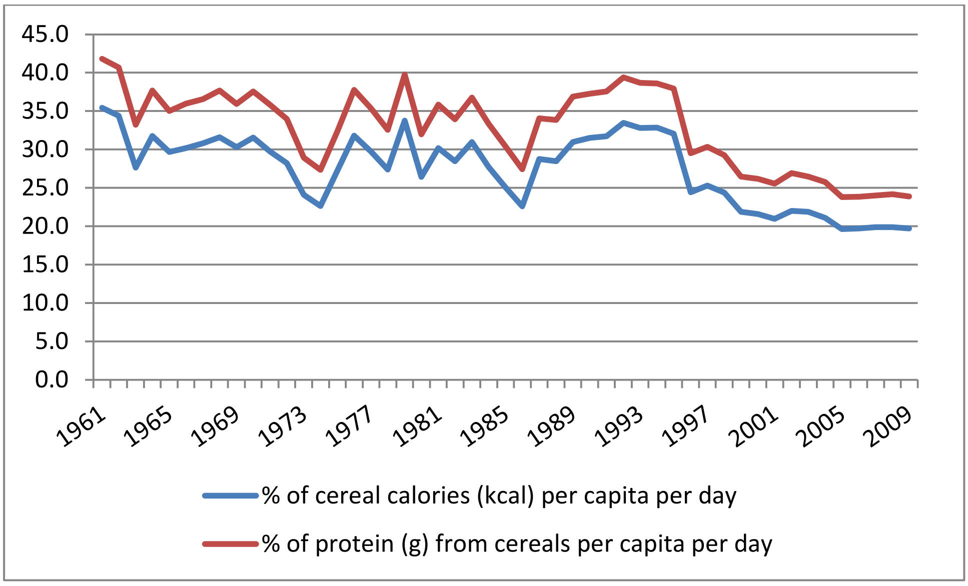


Source: CPS 2014; Observatoire du Marché Agricole (OMA) 2014.

A constraint to sorghum commercialization in Mali is that farmers and agricultural services generally continue to view this cereal as a subsistence crop. There is no organized marketing or trade association for sorghum. The crop has a strong demand in local markets, which are held weekly in villages throughout rural areas. Often, farmers sell sorghum grain in small quantities to generate cash for festivals, marriages, or baptisms, or to meet acute needs for health or school fees. Farm women in some areas are also part-time traders, selling grain from their stores to purchase other ingredients for the sauces that accompany the staple dish or to provide supplementary cash to meet specific needs for themselves and their children (Smale et al. 2008). Thus, although sorghum grain is a form of currency, farmers do not have an organized strategy that enables them to benefit from preferential prices, larger volumes, or premiums that consumers are willing to pay for higher quality grain. Professional grain traders, on the other hand, do. A second constraint has been the state-managed seed system, which is now in the process of transition (Diakité et al. 2008).

Sorghum as a proportion of cereal calories (kilo calorie (kcal) per capita per day) consumed has also declined considerably over time (from 35% in 1961 to 20% in 2009), but remains higher as a proportion of protein from cereals than as a share of calories (Figure 4). In the last year reported (2009), sorghum provided an average of 14% of total kcal of food consumed per capita per day in Mali. In absolute terms, the 1961 figure for sorghum kcal per capita per day is 408, as compared to 357 in 2009. Corresponding figures are 12.0 for protein grams in 1961 from sorghum and 10.5 in 2009. Nationally, sorghum ranks second after millet in terms of its contribution to calories and protein among all cereals grown in Mali, and is followed by rice and maize.

Figure 4. Sorghum as Average Percentage of Calories and Protein from Cereals Consumed in Mali, 1961-2009



Source: FAOSTAT 2013.

3. SORGHUM IMPROVEMENT IN MALI

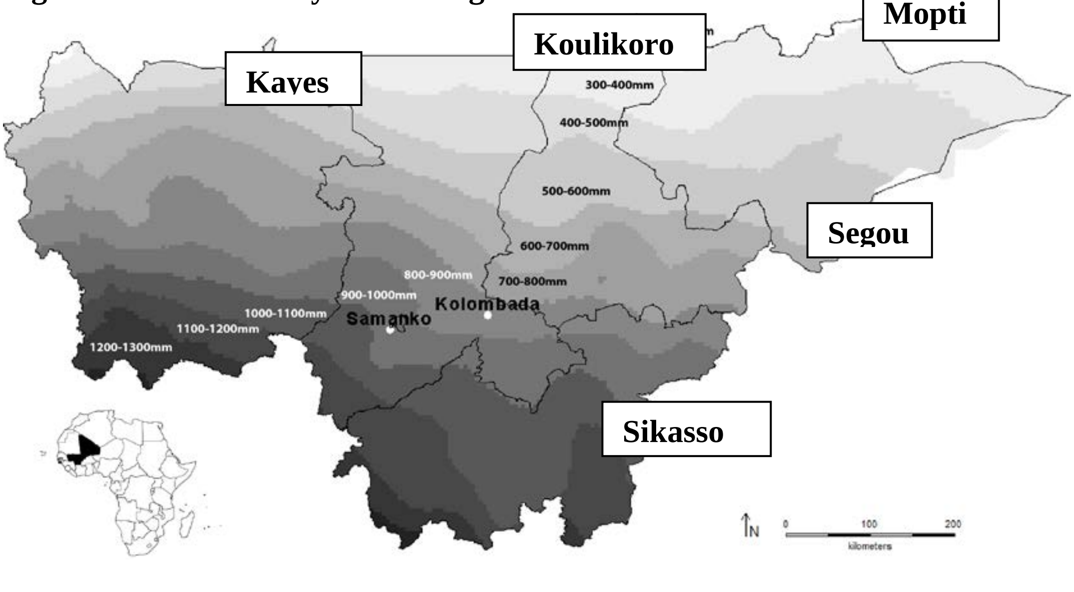
3.1. Agroecological Context

Sorghum is cultivated across Mali's agro-ecologies, from the border with Ivory Coast (1,400 mm annual rainfall) to the border of the Sahara Desert, where rainfall is too low to support support crop cultivation (Figure 5). Adaptation requirements for new sorghum varieties are specific to each ecology, and no single variety can perform over a major share of the sorghum area cultivated in Mali. This simple fact differentiates the context for crop improvement from that of crops such as wheat and rice in South Asia, the historical locus of the Green Revolution.

A compilation of research published in 2008 explores this theme in detail. In that special issue, Bazile et al. (2008) demonstrate how farmers differentiate their crops, varieties, and agronomic varieties by soil type. The authors found that farmers defined soil type according to the position of the field in the toposequence, or profile characteristics related to local topography. Farmers distinguished the shallow soils of the plateaus or higher areas from medium-depth soils and alluvial, low-lying soils (*bas-fonds*). Observed within and among farms, soil differentiation provided one explanation for growing multiple varieties or ecotypes per farm and across a landscape.

The Guinea race of sorghum has a broad geographic distribution, and scientific studies have suggested that it comprises more genetic diversity than other races (e.g., Folkertsma et al. 2005). Currently, sorghum breeding research in West Africa emphasizes the use of genetic diversity within the Guinea race in order to maintain the required grain quality and array of adaptive characteristics. The spatial structure of genetic diversity is another key characteristic of Guinea landraces grown in this region. Often, the range of adaptation of a landrace is only 30-40 kilometers. Sagnard et al. (2008) found that the genetic structure of Malian sorghum is evident among villages more than 30 kilometers apart. Thus, traditional seed systems operate at very local geographical scales.

Figure 5. Rainfall Isohyets and Regions of Southern Mali



Source: Rattunde et al. 2013.

As noted above, a defining trait of Guinea-race sorghum is photoperiod sensitivity, which means that the plant is able to measure the length of periods of light, allowing it to synchronize flowering dates with the end of the rainy season. Photoperiod-sensitive varieties are specifically adapted to a given geographical zone but can cope with a large variation in sowing date, which is critical for farmers who cope with uncertain rainfall conditions in West Africa (Soumaré et al. 2008). When Kouressi et al. (2008) compared the phenology of Malian sorghum varieties collected in 1978 and 2000, they found that despite major droughts, the average cycle duration changed little. They attributed this finding to photoperiod-sensitivity. Moreover, their research indicated that farmers continued to grow combinations of longer- and shorter-duration varieties, attesting to the importance of genetic diversity and a range of ecotypes in supporting farmer adaptation to climatic conditions.

With respect to sorghum cultivation, the agriculturally useful ecologies are classified as presented in Table 1.

Table 1. Characterization of the Main Agro-ecologies in which Sorghum Is Grown in Mali

Agro-ecology and rainfall zone	Predominant soil conditions	Predominant uses of sorghum	Main biotic constraints of sorghum
Sahelian (300–600 mm)	NA	NA	NA
Western Sahel (Northern parts of Kayes and Koulikoro regions)	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, many opportunities for intensification exist.
Central Sahel zone (Northern parts of Segou region)	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)	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	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: Provided by Lamissa Diakité.

In Mali, sorghum is grown throughout all agro-ecologies except the driest, Sahelian zone (300-600 mm rainfall per annum). In the Sudan Savannah, sorghum is the dominant staple crop, and is grown in rotation with cotton, maize, and groundnuts or in association with cowpeas or maize. Fertilizer availability in this zone is facilitated by the cotton sector, and thus research opportunities on intensification of sorghum production have very high potential, especially in the context of high grain prices.

Sikasso and Koulikoro regions have the largest proportions of agricultural land located in the Sudan Savannah zone, and are thus the priority target areas for sorghum breeding and especially for hybrid development in Mali. In order of area cultivated and total production, these are the dominant sorghum-producing regions. As of the 2006 Agricultural Census, the estimated share of crop area planted to sorghum was 31% in Koulikoro and 22% in Sikasso regions. In this zone, research on weed management and profitable options for fertilizer application, as well as integrated pest and disease management, are important. Since sorghum is the primary staple in much of this zone, the nutritional value of sorghum could also contribute to better child nutrition (ICRISAT 2013).

Other zones also present research opportunities for the national sorghum program. In the Northern Guinea zone, sorghum has high biomass production potential in uses other than grain (e.g., fodder, bio-energy, construction materials), is not prone to aflatoxins like other staples grown in this region, and could play a role as a relay or intercrop to maximize the efficiency of water use. The Western Sahelian zone has greater potential for expanding area used for agricultural production, and sorghum is the target staple for this region. Soil fertility and water management improvements are crucial for increasing sorghum productivity in the Central Sahel zone. Sorghum is a minor crop in the Northern Sahel zone, where breeding of extra-early varieties might have an impact on diversification of staples in this area. Sorghum is also a higher priority crop in the recession farming areas that flood during the rainy season (ICRISAT 2013).

3.2. History of Sorghum Improvement

Yapi et al. (2000) provide an overview of the sorghum and pearl millet research in Mali from 1962. ICRISAT began work in the region with the United Nations Development Program (UNDP) and the US Agency for International Development (USAID) in 1975. Until then, research was conducted on a contractual basis with French research institutes such as the *Institut de Recherche Agronomique Tropicale* (IRAT). The West Africa Sorghum Improvement Program at ICRISAT was launched formally in 1988. A year later, the *Centre de Coopération Internationale de Recherche Agronomique pour le Dévelopment* (CIRAD) (formerly IRAT) joined ICRISAT at the Samanko research station. The Sotuba station (in Koulikoro) was also established for sorghum and maize research in the wetter regions, and Cinzana (in Segou) was established for pearl millet improvement in the drier areas.

Sorghum improvement began with the evaluation of new collections of local materials, as well as the introduction of improved genetic materials from other sorghum breeding programs worldwide, such as ICRISAT's program in India, the program in Texas, USA, and the program in France. In response to the devastating droughts and hunger of the 1970s-1980s, the national program focused primarily on raising grain yield. Scientists pursued two main approaches: (1) collecting, testing, *purifying*, and selecting superior landraces for re-release to farmers; and (2) introducing exotic germplasm with characteristics thought to be desirable, including short duration, drought tolerance, short plant height, emergence in high temperature, and grain yield. Releases of this period that were still grown when Yapi et al. (2000) conducted their study, and are still grown today, including Seguetana, Tiemarifing, and the CSM series (Guinea type), all of which are photoperiod-sensitive. Several caudatum-type sorghum varieties, which had been originally released in Senegal and Burkina Faso, were also grown in Mali at that time.

The assessment by Yapi et al. (2000) marked a turning point in the strategy for improvement sorghum in Mali. The authors found that adoption rates were substantially higher for the purified landraces, despite that their yield advantages were often small when compared to yield potential of exotic germplasm. Often, the yield potential of exotic germplasm was not met in the fields of smallholder farmers—in part because it was susceptible to insect damage and molds. In addition, farmers preferred traits associated with Guinea-race types, such as grain quality.

Over the past ten years or so, in order to overcome some of the constraints identified in that study, IER and ICRISAT have pursued the developing of pure Guinea-race hybrids as well as Guinea/caudatum hybrids and varieties, which appear to have a set of growth characteristics that are attractive to farmers and are sufficiently different from their own materials. ICRISAT's breeding program has emphasized two new directions: 1) participatory, multi-locational testing of varieties at an earlier phase of development; and 2) linking farmer and community organizations more closely to research (Weltzien et al. 2006).

By 2001, three government departments and two institutes of higher learning were involved in agricultural research and development in Mali (Stads and Kouriba 2004). The main actor has been and still is the Rural Economy Institute (IER, *Institut d'Economie Rurale*) with its headquarters in Bamako and six regional research stations in the different climatic zones of the country, plus three laboratories and one unit for genetic resources. The national research program collaborates with many international partners such as the CGIAR centers (IITA, ILRI, ICRISAT, WARDA), French research institutes (CIRAD, IRD), and regional institutes (INSAH). IER was an active member in the West-African Sorghum Research Network (ROCARS *Reseau Ouest et Centre Africaine de Recherche sur le Sorgho*), which was coordinated from a base in Mali. Since the phasing out of this network in 2002, collaboration between IER and ICRISAT has been driven by special project funding. The IER sorghum program for Mali now has a range of research partners. Despite the strong reliance on special project funding the IER sorghum breeding group has successfully maintained an effective continuous breeding program.

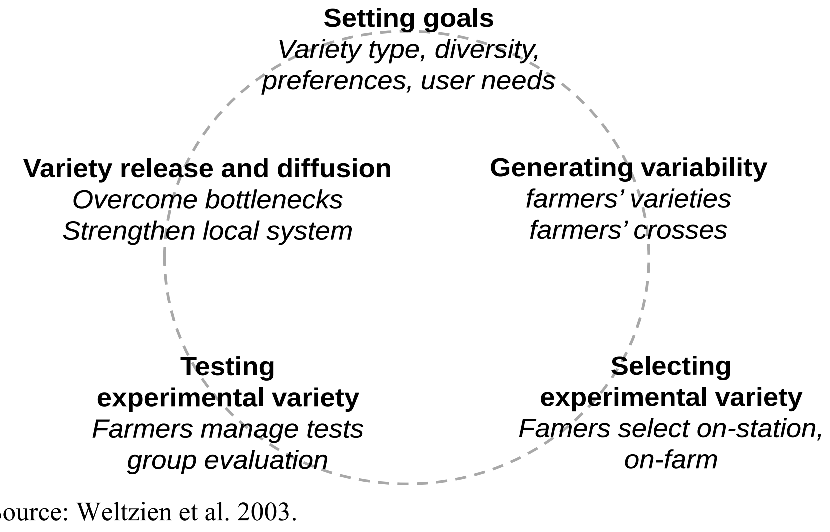
At the time that Stads and Kouriba conducted their study (2004), no private actor was involved in agricultural research and development in Mali. Over the past decade, however, with institutional reform and new seed laws, private sector entrepreneurs have begun to establish themselves in the seed sector where it is linked to the agricultural input business, regional vegetable seed producer groups, and farmer's unions that produce grain or specialize in seed production. There is some interest in sorghum because hybrid seed is now available, the demand for grain quality in the market is substantial, and sorghum grain prices have been rising. However, while agroecology-based breeding with a differentiated range of locally-adapted materials makes good sense from the standpoint of maximum performance and meeting the multiple needs of small-scale farmers, nascent private seed sectors may not be well placed to manage the *roll-out* of numerous varieties simultaneously. Typically, "emerging seed companies are keen to introduce one or two breakthough (first of a type) varieties, which can be followed by other introductions to fill additional market niches" (Joe De Vries[1]).

Data compiled by ICRISAT (2013) indicates that a complementarity has evolved between farmer seed-producer organizations and private enterprises that market seed. The total volume of seed sales of sorghum is growing every year and has reached 70 tons (of which 20t are hybrid seeds) of seed produced by the farmer organization who are partnering with ICRISAT or IER, not including quantities produced by private companies directly, and other farmer organizations. The small private companies produce some of their own sorghum seed, but the increasing volume and numbers of varieties demanded greatly exceed their capacity. They are, thus, buying large quantities of seed from farmer seed cooperatives or unions. The IER/ICRISAT programe has estimated the amount of certified seed required to cover 20% of the area planted to sorghum with improved varieties (at a seeding rate of 5 kg/ha), by agroecology, and has developed a plan that engages functional seed cooperatives, small-scale seed companies, agricultural services in districts and regions, and national and international associations as partners in the development of a decentralized seed supply chain.

As described above, the importance of adaptation to rainfall distributions, soil types, and different uses underscores the need to select varieties in multi-location trials under farmers' conditions. Weltzien et al. (2008a) reviewed changes since 2000 in participatory breeding approaches in West Africa. Compared to earlier programs, in which farmers evaluated materials that had been released but not diffused, the more recent generation of programs began experimenting with farmer-breeder collaboration during the variety development stage, followed by joint variety testing. Weltzien et al. (2008a) depict variety improvement in terms of five continuous, circular stages (Figure 6).

Weltzien et al. (2008b) describe their decentralized breeding strategy as applied in Mali. About 25% of IER source materials are generally crosses between caudatum and Guinea races. ICRISAT source materials are derived from Malian and Burkinabe Guinea races and several high-performing selections from landraces. All sites are located in one rainfall zone, but have different cropping systems and socio-economic contexts.

Figure 6. Process of Participatory Variety Improvement



Source: Weltzien et al. 2003.

[1] Personal communication October 21, 2014.

In the site of Mandé, Cercle (administrative area) of Kati, fewer farmers grow cotton and use of animal traction is limited. In the Cercle of Dioila, cotton is more extensively grown, farmers utilize more animal traction, and more land is available to expand cultivation of sorghum. Koutiala is an historical center of cotton production, where the supply of cultivable land is limited, and most farmers use animal traction. Local partner organizations selected test villages in each of the three sites. The principal partner in Dioila is the Union Local *des Producteurs des Cereales* (ULPC). In Kati, the *Association des Organisations Professionelles des Paysannes* (AOPP) is now the primary partner. Initially, testing was supported by another NGO, *l'Association Conseil pour leDéveloppement* (ACoD), and by *l'Office pour la Haute Vallée du Niger* (OHVN). In Koutiala, farmers engaged in breeding and testing activities were supported by a local NGO, *Association Malien d''Eveil au Developpment Durable* (AMEDD). At first, all farmer-testers were men. When the program recognized that women were more involved in sorghum production than previously believed (Van den Broek 2009), women were brought into the testing and seed production program.

The framework employed for the tests has evolved over the years. From 2003 to 2008, four farmer-testers conducted sorghum trials with 32 test plots in their primary sorghum fields (grand champs, selected by the farmers). The plots were divided into four blocks with eight subplots. Each farmer-tester evaluated 15 varieties and evaluated them for a number of traits. Randomization was prepared by the research organizations and the local partners distributed the seeds and protocols. The field preparation and the seeding, as well as crop management decisions were the responsibility of the farmers. Each village (Mande, Koutiala) or commune (Dioila) has an *animateur villageois* (village agent) who acts as a trainer for farmers, and facilitates information exchange between farmers and technically-trained project personnel. In the Mandé project zone, a farmers' seed cooperative called COPROSEM was established. The cooperative enhances the production of seed of new varieties, increased contacts with input dealers outside the project zone and with other projects, and negotiates fertilizer loans. Additional details are provided in Weltzien et al. (2008b).

Rattunde et al. (2013) summarize recent advances of the new breeding approach and hybrid program since 2009. The two major achievements have been the development of well-adapted hybrids and shorter-statured varieties, both possessing photoperiod-sensitivity and good grain quality. The adaptation comes from locally adapted germplasm, with new variability obtained by moderate introgression of introduced germplasm. The first cytoplasmic male-female parents based on West African Guinea-race landraces and Guinea-Caudatum interracial breeding lines were developed in 2004. New shorter-statured varieties offer potential for significantly enhanced stover quality and new dual-purpose grain/fodder types.

The names and characteristics of sorghum varieties and hybrids that are currently supplied to farmers in Mali are listed in Table 2, according to ICRISAT (2013). Noteworthy improved varieties (Diakité 2009) include several of the CSM series, such as CSM 63E (Jakumbe), Tieble, Jiguisseme, Tiemarifing, Gadiaba, and Seguétana CZ. Additional data are found in the official catalog, but these are not complete for recent releases (Direction Nationale de l'Agriculture 2013).

Table 2. List of Major 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 Sensi-tivity 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
NIELENI	V	Sahelian	600-800	L	3	2011
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-COURA	V, R	Sudanian	800-1000	L	1.8	2011
TIANDOUGOU	V,R	Sudanian	800-1000	L	1.8	2002
DARRELLKEN	V	Sudanian	700-900	L	3.5	2002
N'TENIMISSA	V	Sudanian	800-1000	L	3.5	1995
JIGISEME (CSM 338)	V, R	Sudanian	800-1000	M	3.7	1984
NIATCHITIAMA	V	Sudanian	800-1000	M	2	2002
SEGUETANA-CZ	V	Sudanian	600-900	M	3.5	1989
TIEBLE (CSM 335)	V	Sudanian	800-1000	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	800-1000	M	4	2002
TOROBA	V	Sudanian	700-1000	M	4	2005
LATA	V,R	Sudanian	800-1000	M	3	2009
DIEMA	V,R	Sudanian	800-1100	L	4	2012
BOBOJE	V	Sudanian Savannah	800-1200	H	3.8	2005
ZARRA	V	Sudanian	800-1000	M	4	2002
TIEMARIFING	V	North Guinean	1000-1200	H	4.5	1984
SOUMALEMBA	V	North Guinean	1000-1200	H	4.5	1999
DOUAJE	V	North Guinean	800-1200	H	3.5	2010
NIELENI	H	Soudanien	700-900	L	3	2011
FADDA	H	Sudanian	800-1000	M	3	2008
SEWA	H	Sudanian	800-1000	M	2.5	2008
SIGUI-KOUMBE	H	Sudanian	800-1000	M	2.5	2008
HOUDÔ	H	Sudanian	800-1000	M	2	2012
OMBA	H	Sudanian	800-1000	M	4	2012
PABLO	H	Sudanian	700-1000	M	4	2012
YAMASSA	H	Sudanian	800-1000	M	5	2012
CAUFA	H	Sudanian	800-1000	M	4	2012
NIAKAFA	H	Sudanian	800-1000	M	4	2012
GRINKAN YEREWOLO	H	Sudanian	800-1000	M	2	2010

Source: Eva Weltzien-Rattunde. Personal Communication.
*Class L=Least, M=Moderate, H=Highly.

3.3. Previous Studies about Sorghum Seed Use and Seed Systems

Few studies have systematically assessed the adoption of improved sorghum varieties on a large geographical scale in Mali. A number of case studies funded by ICRISAT have contributed insights into the use of sorghum varieties by farmers and their diversity, the role of women in sorghum production, and the contribution of local seed systems to variety diffusion. Below, we begin by summarizing the main findings of previous adoption studies. We then highlight some of the findings from the second set of studies, which have contributed to the strategies and approaches pursued today by IER/ICRISAT. As noted above, current strategies are designed to encourage more widespread use of improved varieties through decentralized breeding, seed production, and supply.

3.3.1. Adoption

Matlon (1990) reported that, "under normal rainfall conditions, and with low to moderate input levels under farmers' management, the yield advantage of most improved cultivars rarely exceeds 15% and is often negative" (p. 27 ; see also Matlon 1985). He estimated an overall adoption rate for improved sorghum and millet in the region that did not exceed 5%, citing the region's "enormous agroclimatic diversity" and the poor adaptation of introduced materials among the primary constraints. However, as noted by Yapi et al. (2000), Matlon's estimates referred only to introduced varieties, and did not include selections from superior local landraces. Matlon's research and that of Sanders, Shapiro, and Ramaswamy (1996) emphasized the need to combine improved seed with soil fertility and water management practices.

When Yapi et al. (2000) grouped materials by breeding strategy, they found much higher overall rates of adoption in Mali. In their sample survey covering 53 villages, data indicated that 34% of sorghum growers in the Mopti region, 36% of farmers in Segou region, and 52% of farmers in Koulikoro region grew improved varieties. Most adopted varieties were based on improved selections of local Guinea ecotypes, as compared to crosses based on the introduced, caudatum types. Adoption rates for improved varieties were higher in the more favorable rainfall zones of the Koulikoro region than in either Segou or Mopti regions, and rose between 1990 and 1995. Notably, less than 1% of farmers used chemical fertilizers, although almost all used manure.

The continued popularity of local ecotypes compared with introduced cultivars was explained by preferences for food quality, farmer familiarity with these well-adapted varieties, and their tall stalks, which provided good fodder and other useful materials. In Koulikoro, where sorghum competes with maize, early maturity and higher yield were identified as priority traits. Farmers cited lack of improved seed and related information as major constraints to adoption. By far the most important source of information about seed in Koulikoro and Mopti regions was other famers within the village; the *Service Semencier National,* (SSN) (National Seed Service) was present in Segou, and seed service and extension agents were more prominent as sources of variety information.

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 1,047 farmers in the zones of San and Sikasso. Major varieties included included N'ténimissa, CS 388, ICSM 1063, and Malisor 92-1. Comparing this rate to the adoption rate for improved varieties of rice, 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.

In the areas where this study has been conducted, Some (2011) analyzed the determinants of adoption and the varietal diversity of sorghum in the cercles of Kati and Dioila, including 201 production units and 85 women farmers. He found that presence of test activities in the village raised the chances of adoption by 0.29. Access to purchased inputs increased it by 0.19, and availability of improved seed had a much smaller effect (0.08). The last finding could be explained by the relative strength of the local seed system, in which farmer-to-farmer exchange plays a much stronger role traditionally than other sources of seed.

Farmers appear to frequently change variety portfolios of sorghum ecotypes planted, especially following drought. Ehret (2010) analyzed changes in sorghum diversity in three of the villages of the Mandé region. She found that variety diversity at the village scale increased in all three project villages from 2004-2010, and that variety diversity per farm clearly increased in two of the three villages. Ehret concluded that the process of varietal choice over the years is dynamic; most farmers in the three villages she studied decided to experiment varieties with different cycle lengths and with a different number of varieties on the field. Few farmers retained the same portfolio over the period. Some et al. (not dated) found that after a drought season, most farmers shifted toward cultivation of a higher number of varieties, emphasizing improved materials with a short growing cycle. Diversification was more intense in villages with more active selection programs. Social relationships seem to have an influence on farmers' information exchange and consequently on the diversity of sorghum varieties cultivated by households (Ehret 2010).

3.3.2. Seed Systems

Siart's (2008) thesis examined the function of local seed systems for sorghum in southern Mali from the perspective of how they could be leveraged to encourage the diffusion of improved varieties. 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. After a drought year, they are more likely to accept seeds from outside of their families and village, and to purchase seed. Siart (2008) did find that farmers expressed interest and a willingness to pay a higher price for quality seed of improved varieties. However, the demand was likely to limited and too unpredictable to support private sector interest, suggesting the need to begin seed commercialization through a farmer cooperative, in conjunction with seed of other crops, or in association with grain trade. Overall, Siart concluded that the absence of a formal seed system is accepted as a fact by farmers in the project zones. Thus, she concluded that there is potential to organize seed production in a decentralized way, based on multiplication and sales by local farmers' organizations. A study by Delaunay et al. (2008) found that even in the cash-oriented economy of a village in the cotton-producing zone of Burkina Faso, traditional exchange systems for sorghum seed persisted. Consistent with the notion that there is potential for decentralized seed production, Diallo (2009) tested the quality of farmer-produced seed. She found that farmer-produced seed generally met the standards established by the National Seed Service in Mali.

Jones (2014) studied seed systems and strategies for disseminating seed in sites of Mali, Burkina Faso, and Niger, funded by the McKnight Foundation and HOPE project. These included agro-dealer sales of mini-packets, sales by farmer unions, and farmer-to-farmer exchange or sales by farmer testers. Formal, market-based systems and informal, exchange-based seed systems are often treated as a dichotomy, but the framework proposed by Jones integrates them.

Her thesis research confirmed that emerging local markets for seed (as represented by the seed sales strategies included in the project) continue to be socially embedded. In this context, the promotion of a narrow value chain approach, or any approach that is confined to formal seed systems, will exclude many farmers. In designing more inclusive programs, it is important to recognize that there are important differences in seed access choices not only according to rainfall and the physical development of market infrastructure, but also between men and women farmers, farmers who are members of unions and those who are not, and farmers with and without with access to social infrastructure.

Jones (2014) found that many farmers appreciate the reliability that comes with certified seeds, as well as with standardized market transactions, and have begun to move toward integration into a formal seed system. However, the sale of mini-packets and the production of improved variety seeds by local seed producers have also provided points of integration between a new, formal seed system and local, traditional seed systems. For example, points of integration occur when seed is sold directly from a seed producer's field, or when seed that has not been certified by the national certification agency is exchanged based on trust and incorporated into the local, socially-based seed system. Similarly, exchanges of measures of grain for measures of second-generation, improved seed allow the genetic resource initially accessed through the purchase of mini-packets in the formal seed system to enter the local seed system. Given the history of farmer-breeder collaboration in the project sites, many farmers are already familiar with the traits of the new varieties and are able to incorporate them into their local seed systems through exchanging, giving, and saving.

3.3.3. Women's Use of Sorghum Seed

Researchers funded by ICRISAT's program have begun to recognize the evolving role of women in sorghum production in Mali, and the potential for women's involvement in testing, seed production, and diffusion. Van den Broek (2009) found few women engaged in exchange of seed. Women usually received sorghum seed from their husbands or their parents, which could serve as a means of introducing a new variety into a village. Noting the importance of sorghum in household food security, Siart (2008) expected to find that women expressed a demand for early-maturing varieties. Instead, they were interested in appropriate varieties and preferred an independent source of seed outside the decision-making structure of their production units. All women interviewed by Ehret (2010) in the three villages cultivated sorghum in 2004 and 2010, and most grew the same variety as the men in the household. Some (2011) found that women tended to grow groundnut in association with sorghum on their small individual plots, tended to planted only one sorghum variety at a time, and depended for access to farm equipment on the decisions of the head of the production unit.

Van den Broek's (2009) thesis explored the potential for the sorghum program's strategies to improve the agricultural conditions of women in the project zone. Traditionally, in the sorghum-based systems of southern Mali, men are responsible for grain production and food security from the crop harvested on family fields. Married women contribute their labor on the family fields where they also cultivate individual plots on which they grow crops that provide the legumes, groundnuts, and vegetables to complement the staple food and provide a source of cash to pay for school fees and other needs of their children. In contrast with this stereotype, Van den Broek (2009) found that all women she interviewed grew sorghum in their individual plots. Women explained that due to droughts and soil degradation, harvests on the collective fields were often insufficient to feed the extended family. Except when contributing to the family stocks in times of shortage, however, women decide what they grow and control the harvest from their plots. Their harvests provide them with income to buy the ingredients for their food (spices, salt, sugar, and oil), clothes for themselves and their children, gifts, and items for their daughter's dowry.

In her thesis, Donovan (2010) sought to inform sorghum breeders about how to better engage women farmers in participatory plant breeding. After surveying over one hundred women in five villages, Donovan (2010) found that most women cultivate at least a small amount of sorghum, typically receiving their first sorghum seed from men in the household, but often saving their seed from year to year. Most women surveyed had heard of the testing program, but had not been part of the breeding program or received any improved seed, even if they had husbands or male family members involved in the program. Most women belonged to at least one cooperative, but factors such as wealth and age seemed to have an effect on membership. Clearly, engaging women independent of their production units, as managers of their individual plots, is fundamental for ensuring their participation.

4. METHODOLOGY

4.1. Farm Survey

The farm survey conducted for this study was used to measure rates of adoption of sorghum ecotypes and seed use. The survey represents a baseline census of all farm households in 58 villages located in the principal sites where IER/ICRISAT has conducted its pilot-testing activities from 2009 to 2013.

Initially, 60 villages were identified where (a) computerized records indicated that the IER/ICRISAT program had conducted research and extension activities through partnerships with farmers' associations from 2009, and (b) population sizes were under 1,000 persons (assumed to be equivalent to roughly 100 households). Of these, two were eliminated when field visits revealed that farmers in these villages had not participated directly in activities led by farmers' associations.

The villages are located in the Cercles of Kati, Dioila, and Koutiala, which constitute three of nine Cercles that compose the sorghum belt of Mali. Kati and Dioila are located in the region of Koulikoro, and Koutiala is found in the region of Sikasso. Koutiala is the most populated Cercle with a density of more than 90 persons per square km due to the well-developed export value chain for cotton. Annual rainfall in this zone varies on average between 700 to 900 mm. Major cereal crops grown are maize, sorghum, and pearl millet; cotton, sesame, groundnuts, and vegetables are cash crops. While soils in the higher reaches of the toposequence tend to be degraded and deficient in plant available phosphorus, degraded soils in the lower reaches that are used for cotton and maize cultivation tend be regularly fertilized, and soil conservation practices a more widely applied here than in the other two regions. Sorghum tends to be primarily cultivated on more degraded soils. Pearl millet production can also benefit from the residual effects of fertilizers applied to cotton and maize. The Cercle of Dioila is moderately populated, with population densities that reach 65 persons per square kilometer (RGPH 2009). Rainfall ranges from 700 to 1,000 mm. Cereal crops grown are sorghum, maize, and pearl millet. Cotton, ground nut, and cowpea are also produced. Soils are suitable for sorghum production. In the Mandé zone of the Cercle of Kati, soils are clay to silt, and rainfall varies between 750 to 1,000 mm. The population density is also relatively high due to vicinity with Bamako. Major cereal crops are sorghum, millet, and maize. High value crops include vegetables and mango, and women focus heavily on groundnut production for the peri-urban market.

Teams composed of an animateur (village agent) and enumerators then implemented the survey instrument included in Annex A in each household, totaling 2,430 family farm enterprises (*exploitations agricoles familiales*, or EAFs). The instrument includes: (a) a list of all household members with socio-demographic information; (b) a list of all plots by crop planted, with information on size and soil type; and (c) a list of all sorghum varieties grown from 2009 to 2013, with information on seed source, mode of acquisition, changes in area planted over the past five years, and stated reasons for changes.

4.2. Assessment of Investment Rate of Return

Following Yapi et al. (2000), we apply an economic surplus model (Alston, Norton, and Parden 1995; Masters and Ly 1993) to derive summary measures of the ex-post benefits of investing in sorghum improvement in Mali.

In any economic surplus model, the key parameters that influence the magnitude of the economic benefits are: (1) the adoption rate in terms of area under new genetic materials; (2) average yield gains (or avoided losses) following adoption; (3) pre-investment (seed cost) levels of production and prices; (4) time lags from initial investment to adoption; and (5) the time value of money, or discount rate. Price elasticities of supply and demand are also needed to generate estimates.

Table 3 presents the parameters used to project the economic impacts in this study. The maximum adoption rate (33%) is based on results of the village census (reported below), which is also consistent with expert opinion for the nation as a whole (Ndjeunga et al. 2012). Key informant interviews with farmers in study villages provided representative budgets with associated yield advantages and per unit cost changes (Annex B). Most applicable for better-off farmers in relatively good growing conditions, these estimates are likely to overstate yield advantages attained over a broad range of farmers and farming conditions. Rattunde et al. (2013) reported yield advantages of individual hybrids of 17% to 47% over the local check, with the top three hybrids averaging 30%. For hybrids, we utilize a yield advantage of 30%, and for improved varieties, 20%. Expert opinion suggests up to 50% yield advantages with improved varieties, but only under better conditions. With respect to changes in production costs, which are also affected by yield advantages, we apply an average of 5% due to seed and higher harvest labor requirements. While application of manure, compost, and chemical fertilizer is advised along with recommended herbicides and weeding practices (as shown in representative budgets, Annex B), many farmers are unable to apply all techniques.

Price series for sorghum during the analytical period (1997/98 through 2013/14) were obtained from *Observatoire du Marché Agricole* (OMA). Current prices (most frequently $250/t) were collected during key informant interviews. Area and production data were provided by the *Cellule de Planification Statististique du Secteur du Développement Rural* (CPS-SDR). Series are shown in Annex B.

Table 3. Parameter Values Used to Estimate Investment Rate of Return

Parameter	Value
Productivity change due to investment (%)	30 (hybrid), 20 (improved) 21% area-weighted average
Change in sorghum production cost per ton harvested (%)	5
Maximum adoption level (%)	33
Gestation lag (years until start of adoption)	8
Adoption lag (years until maximum adoption)	19
Price elasticity of supply	0.5
Price elasticity of demand	−0.4
Discount rate (%)	5
Total investment (US$ million nominal)	3.5
Time path of benefits	2005/6─2024/25
Time path of costs	1997/98─2011/12

Source: Authors.

A search of both published and unpublished literature revealed no estimates of price elasticities of demand and supply in Mali, or elsewhere in the region (Burkina Faso, Niger). Yapi et al. (2000) assumed a price elasticity of sorghum supply to be 0.40 given that sorghum is a staple food and the objective of many of Mali's smallholder farmers is to meet subsistence needs of family members (a value less than one implies inelastic supply). A recent study by Munyati et al. (2013) used farm-level data to estimate a supply response in terms of acreage response on commercial as well as subsistence-oriented farmers in Zimbabwe. The authors estimated a long-run price elasticity of supply of 0.51, including both types of farmers. For the purpose of this study, we apply 0.50. As did Yapi et al. (2000), we applied a price elasticity of demand of (-) 0.75. Again, this reflects the fact that demand is fairly inelastic (less than 1).

Research investments costs were borne by IER and ICRISAT. Over the time period studied, improved sorghum varieties were diffused primarily by Government Extension services (regional offices), and farmers unions (AOPP, AMEED, ULCP). Data on the annual costs of research on sorghum incurred by IER for the period 1997-2012 were obtained from a discussion with the chief of national research program (*Programme Sorgho de l'IER*). Cost series include salaries of scientists and technicians, as well as expenditures on tests and demonstrations. ICRISAT annual costs were provided by ICRISAT-Mali. Total project cost was used to derive annual cost depending on research intensity. The estimated cost of sorghum research investment in Mali by ICRISAT is estimated at $226,133 a year, as compared to $50,000 for IER. Discussions with the regional extension directors led to estimated annual costs of diffusion at $40,000 a year. Extension costs associated with Government extension services reflect the investment flow in research and extension; at an early stage, investment is small in magnitude. Amounts invested each year peak and then decline for a given set of varieties or hybrids. Costs series are shown in Annex B.

Formulae for deriving benefits are drawn from Alston, Norton, and Parden (1995), assuming a closed economy (as compared to an export commodity traded in an open economy). Yield changes lead to a downward shift in the supply curve, equivalent to a reduction in cost of production. Annual supply shifts were projected for the period from 2005 to 2024 for research starting in 1997.

Benefits were calculated from 2004 through 2024 and costs were calculated from 1997 through 2011. Benefits and costs were discounted at a real, social discount rate (r) of 5% per annum to derive the net present values (NPV) in 1997 terms over the years considered (t). The aggregate NPV, including three target zones (i) for sorghum production, was thus derived as:

$$NPV = \sum_{t=2005}^{2024} \sum_{i=1}^{3} \left(\frac{\Delta ES_{i,t}}{(1+r)^t} \right) - \sum_{t=1997}^{2011} \left(\frac{C_t}{(1+r)^t} \right)$$

The change in economic surplus (ΔES) is equal to $[P_0 Q_0 K_t(1+0.5Z_t\eta)]$, where K_t is the outward supply shift representing the product of cost reduction per ton of output as a proportion of product price (K) and technology adoption at time t (A_t); P_0 represents pre-research price; Q_0 is pre-research level of production; η is the price elasticity of demand; and Z_t is the relative reduction in price at time t, which is calculated as $Z_t = K_t\varepsilon/(\varepsilon+\eta)$, where ε is the price elasticity of supply.

ΔES was calculated over the benefit period beginning in 2005/2006 (following an adoption lag of eight years from the initial investment in 1997, to account for development and testing of improved varieties) and ending in the 2024/25 season, when the maximum adoption rate of 33% is attained. Costs begin in 1997/1998, but end for the set of varieties considered in 2011/2012. Costs and benefits are discounted at the social discount rate (r) of 5% per annum. *NPV* is understood in terms of 2009 values.

The aggregate internal rate of return (*IRR*) was calculated as the discount rate that equates the aggregate net present value (NPV) to zero. The aggregate benefit–cost ratio (B/C) was calculated as the ratio of the present values of aggregate benefits to the present values of research and extension costs:

$$B/C = \frac{NPV}{\sum_{t=1997}^{2024}\left(\frac{C_t}{(1+r)^t}\right)}$$

In addition to these parameters, the impact of the sorghum improvement program on rural poverty reduction in Mali was estimated, as shown below. First, the marginal impact on poverty reduction of an increase in the value of agricultural production was calculated using poverty reduction elasticities associated with growth in agricultural productivity, following Alene and Coulibaly (2009) and Thirtle, Lin, and Piesse (2003). In a meta-analysis undertaken with data from a number of countries in Africa south of the Sahara, Thirtle, Lin, and Piesse (2003) found that a 1% growth in agricultural productivity reduces the total number of rural poor by 0.72%. We found no more recent estimates of poverty reduction elasticities cited in the published literature or known to these authors.

Under the assumption of constant returns to scale, a 1% growth in total factor productivity leads to a 1% growth in agricultural production. In the second component of the equation, the reduction in the total number of poor was calculated by considering the estimated economic benefits as the additional increase in agricultural production value. For the zones in Mali, the number of poor people lifted above the \$1-a-day poverty line was thus derived as:

$$\Delta N_p = \underbrace{\underbrace{\underbrace{\left(\frac{\Delta ES}{\text{Agric.value added}} \times 100\%\right)}_{\text{Gains from R\&E as \% of agricultural production}} \times \underbrace{\frac{\partial \ln\left(\frac{N_p}{N}\right)}{\partial \ln(Y)}}_{\text{Poverty elasticity=0.72\%}}}_{\text{Poverty reduction as \% of the poor}} \times N_p}_{\text{Number of poor escaping poverty}}$$

Where δnp is the number of poor lifted above the poverty line, np is the total number of poor, n is the total population, y is agricultural productivity, and δes is as defined above. The poverty elasticity of 0.72% is interpreted as the marginal impact of a 1% increase in agricultural productivity in terms of the decline in the number of poor people as a percentage of the total number of poor people (np), rather than as a percentage of the total population.

5. RESULTS

5.1. Survey Findings

Findings from the village census survey are summarized in this subsection. Since the survey represents a census within villages rather than a sample, the only errors in the data are measurement (as compared to sampling) errors, and statistical tests are not appropriate. Variety names were verified and classified according to race, improvement status, maturity, and storability by ICRISAT-Mali.

Of the 2,430 households listed and interviewed in 58 villages, 2,014 (83%) grew sorghum in the 2013 main growing season. Considering all plots listed for that season, 24% were planted with sorghum, 21% with groundnut, 16% with maize, 9% with millet, and 10% with cotton. As expected, the share of sorghum plots was higher in Dioila (27%) than in the other sites, the share of groundnut plots was considerably higher in Kati (36%), and the share of cotton plots was highest in Koutiala (14%). Gender-related changes are worth noting: the team found that 13% of sorghum plots were managed by women (87% by men), and that women managed 51% of groundnut plots (with younger men, in particular managing 49%). Thus, women were more heavily represented among sorghum plot managers and less represented among groundnut plot managers than expected. Almost all vegetable plots, including okra, and a third of rice plots, but surprisingly few cowpea plots, appear to be managed by women.

Slightly over one quarter of households (26.2%) had grown varieties classified as improved (including hybrids) at least once during the past five years (2009-2013). However, adoption of improved materials is clustered by household. That is, when one member of a household grows a new variety, other members are also likely to do so on the plots they manage. Thus, the adoption rate per sorghum plot is greater than per household.

Table 4 reports the characteristics of all sorghum varieties grown by farmers over the 2009-2013 period, analyzed by plot. Farmers reported a total of 136 named varieties on up to 3,496 plots per season (counting plots anew in each season). Not all attributes are known for all varieties reported, since many are local varieties. Some local varieties are likely to be improved varieties that farmers now refer to with local names. Thus, numbers by trait do not total to 3,496.

Newly released hybrids were grown on 4.2 % of all sorghum plots planted from 2009 to 2013. Including these, 28.7% of all sorghum plots were planted to improved materials. Hybrid seed use rates by plot were 4.7% over the period for sorghum plots in Koutiala, as compared to 3.4% in Kati and 4.5% in Dioila. On the other hand, use of improved varieties in Kati was 39.5% of sorghum plots, as compared to 24.1% in Dioila and only 11.2% in Koutiala.

In terms of race, the indigenous Guinea race was dominant among the improved varieties and hybrids grown by farmers (95%). About 61% of sorghum plots were planted with varieties with medium-maturity (although these this trait is missing for many varieties), with 21% extra-early-maturing and 18% late-maturing. This result attests to farmer preferences for diversity in cycle length. Most types now store relatively well (96%) and are tall-statured (97%).

Table 4. Characteristics of Sorghum Varieties Grown by Farmers, by Plot, from 2009 to 2013

Category	Frequency	Percent
Race		
Guinea	3,308	95.22
Intermed	130	3.74
Caudatum	14	0.4
Durra	22	0.63
Total	3,474	100
Improvement Status		
Local	2,485	71.26
Improved variety	854	24.49
Hybrid	148	4.24
Total	3,487	100
Maturity		
Extra early	408	21.16
Medium	1,178	61.1
Late	342	17.74
Total	1,928	100
Storage quality		
Good	3,339	96.11
Not so good	135	3.89
Total	3,474	100
Plant height		
Tall	3,323	95.65
Short	84	2.42
Intermediate	67	1.93
Total	3,474	100

Source: Authors. Names identified and characterized by ICRISAT-Mali.

Over the five-year period, the percentage of sorghum area planted to hybrid seed grew from 1.52 to 2.65%, fluctuating slightly among years (Table 5). All improved varieties and hybrids represented 28% of sorghum area by 2013. This adoption rate is very close to that reported by Ndjeunga et al. (2012) for Mali as a whole (33%), which was based on expert opinion. In addition, it is important to recognize that many of these are new materials that replaced older improved materials, and some of those classified by farmers as local, and given local names, could be advanced generations of improved germplasm.

Average areas of plots planted to each type of sorghum variety are shown in Table 6, for each year from 2009 to 2013. Means areas planted to hybrids and improved varieties rise more rapidly than the overall average. Hybrid seed was planted on an average of only 0.50 ha in 2009 as test seed, but the average area more than doubled by 2013.

Table 5. Percentage of Total Sorghum Area Planted by Variety Type, 2009-2013

	2009	2010	2011	2012	2013
Hybrid	1.52	1.45	1.85	1.71	2.65
Improved variety	21.3	21.6	22.1	23.1	25.7
All improved	22.8	23.0	24.0	24.8	28.3
Local varieties	77.2	77.0	76.0	75.2	71.7
All varieties (%)	100	100	100	100	100
All varieties (ha)	6,179.69	6,244.58	6,689.73	6,843.17	7,307.46

Source: Authors. n=3,502 plots.

Table 6. Change in Mean Plot Areas (ha) Planted to Different Types of Sorghum Varieties

	2009	2010	2011	2012	2013
Local	1.99	2.01	2.13	2.16	2.22
Improved variety	1.34	1.37	1.51	1.59	1.88
Hybrid	0.50	0.48	0.67	0.65	1.12
Overall average	1.77	1.79	1.92	1.96	2.09

Source: Authors. n= 3,502 (each year).

This pattern is confirmed by the data shown in Table 7. More than half of farmers who planted hybrids reported that the area allocated to this variety type increased over the 5-year period. By comparison, about 50% of farmers reported that areas planted to local sorghum varieties remained constant. Just over one-third of farmers increased the area they planted to improved sorghum varieties over the period (35%), compared to only 30% reporting increases for local varieties.

Use rates for improved varieties and hybrids do not differ meaningfully between men and women plot managers. 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 (Table 8).

Table 7. Changes in Area Planted to Sorghum Variety Types by Farmers, 2009-2012

	Increase	Decrease	Constant	Total
Local	688.00	463.00	1,175	2,326
	29.58	19.91	50.52	100
Improved variety	277.00	175.00	336	788
	35.15	22.21	42.64	100
Hybrid	60	14	38	112
	53.57	12.5	33.93	100
Total	1,025	652	1,549	3,226
	31.77	20.21	48.02	100

Source: Authors. n=3,500 plots.

Table 8. Sex of Sorghum Plot Manager, by Variety Type

		Local	Improved	Hybrid	Total
Men	n	2,073	717	108	2,898
	%	71.53	24.74	3.73	100
Mean plot size(ha) 2009-2013		2.22	1.66	0.82	2.04
Women	N	250	72	6	328
	%	76.22	21.95	1.83	100
Mean plot size(ha) 2009-2013		0.98	0.68	0.29	0.90
Total	N	2,323	789	114	3,226
	%	72.01	24.46	3.53	100

Source: Authors. n=3,500 plots.

In the initial year of use, 24% of seed lots (referring to the seed of a specific variety planted in a plot) were acquired through cash purchases as minipacks or in other ways, and overall, about two-thirds of hybrid seed was purchased for cash (Table 9). According to farmers, about a third of the seed of improved varieties was 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 primary means of acquiring seed. Gifts and exchange represented over 80% of the acquisitions of local sorghum seed. It is noteworthy that organized visits (by outsiders, such as ICRISAT scientist) were not important routes of acquisition. However, it is important to recognize that differentiating the origin of seed from the physical location of a seed source is sometimes difficult during interviews, and that these data should be interpreted with caution.

Table 9. Mode of Sorghum Seed Acquisition, Initial Use, by Improvement Status

Improvement status	Initial mode of acquisition					
	Minipack purchase	Other purchase	Gift	Exchange	During an organized visit	Total
Local	62	353	1,415	492	2	2,324
	2.67	15.19	60.89	21.17	0.09	100
Improved variety	60	238	353	138	1	790
	7.59	30.13	44.68	17.47	0.13	100
Hybrid	9	64	38	0	0	111
	8.11	57.66	34.23	0	0	100
Total	131	655	1,806	630	3	3,225
	4.06	20.31	56.00	19.53	0.09	100

Source: Authors. N=3,500 plots.

Farmer seed-producers represented 11% and 7% of seed sources for improved and hybrid seed, but other farmers in the same village (either family or non-family) were the dominant sources of sorghum seed for all types, including improved germplasm. Combined with the data presented in Table 8, this suggests that farmers are also acquiring seed through cash payments to other farmers. Farmers' unions, merchants, input dealers, seed fairs and extension services each represent relatively minor sources of sorghum seed relative to other farmers (Table 10).

Again, these data must be interpreted with caution given the difficulty of differentiating origin from seed sources during farmer interviews. An example is the classification of source as *inheritance*, which is an origin, strictly speaking. In addition, improved varieties or hybrids are not likely to be inherited, but are likely to be transferred within households among family members, such as from male household heads or work team leaders to women or younger men.

Table 10. Seed Source, First Year Planting, by Improvement Status

Source	Local	Improved Variety	Hybrid	Total
Inheritance	375	49	4	428
	16.14	6.2	3.6	13.27
Farmer seed-producers	18	89	8	115
	0.77	11.27	7.21	3.57
Another farmer in same village, not family	1,154	245	24	1,423
	49.66	31.01	21.62	44.12
Another farmer in another village, not family	102	26	0	128
	4.39	3.29	0	3.97
Another farmer, family, same village	484	119	3	606
	20.83	15.06	2.7	18.79
Another farmer, family, another village	82	27	1	110
	3.53	3.42	0.9	3.41
Extension service	40	152	58	250
	1.72	19.24	52.25	7.75
Farmers' union	32	72	12	116
	1.38	9.11	10.81	3.6
Agro-dealers	4	4	0	8
	0.17	0.51	0	0.25
Input store	4	1	0	5
	0.17	0.13	0	0.16
Merchant	21	4	0	25
	0.9	0.51	0	0.78
Seed fair	0	2	0	2
	0	0.25	0	0.06
Other	8	0	1	9
	0.34	0	0.9	0.28
Total	2,324	790	111	3,225
	100	100	100	100

Source: Authors. N=3,500 plots.

5.2. Investment Rate of Return

Considering the period spanning 1997-2013, and assuming the parameter values shown in Table 3, we estimate a net present value of USD $16 million from investing in sorghum improvement in Mali (Table 11). The internal rate of return is estimated at 36% per year with a benefit–cost ratio of 6:1. The benefit–cost ratio of 6:1 indicates that each dollar invested in the pilot project to develop improved sorghum varieties and hybrids generates and average of $6 in terms of net benefits. This contribution to growth in agricultural productivity was sufficient to lift an estimated 20,000 Malians out of $1-a-day poverty, given assumptions described in the methods section. The total number of persons leaving poverty from 2004 to 2024 (the benefit period) is estimated to be 536,887, representing 5% of the poor population of Mali in 2014.

Our baseline assumptions are relatively conservative. Recognizing that the supply shift parameter—a function of yield gains and price elasticity of supply—is the major determinant of research benefits, the model was estimated under alternative scenarios related to proportional yield gains. Table 11 also presents results of a sensitivity analysis to explore how findings change with variation in key parameter values.

Table 11. Returns to Investing in Improved Sorghum Varieties and Hybrids in Mali, 1997-2024

Scenarios	Net Present Value (million USD)	Rate of Return	B-C Ratio	Poverty Reduction (‘000) per year of benefit
Baseline	16	25	6	20
Scenario relative to baseline parameters (Table 4)				
(1) Increase in average yield advantage from baseline of 10%	161	59	63	200
(2) Production cost per ton increased to 10%	4	11	2	6
(3) Sorghum price increase of $50 per ton	19	27	8	24
(4) Discount rate increase from 5% to 10%	7	NC	4	NC
(5) Discount rate increased from 10% to 25%	1	NC	1	NC

Source: Authors.

Although the adoption rate has a major effect on indicators of investment returns, we believe that long-term adoption ceilings, as a proportion of total area planted to sorghum in Mali, may not exceed 30-40%. This adoption rate has been borne out by Yapi et al. (2000), the village census undertaken as part of this study (which covered a 5-year period in 58 villages), and expert opinion (Ndjeunga et al. 2012), and may reflect underlying soils, agro-ecological and economic constraints that affect farmer decision-making.

Thus, we varied other parameters in our sensitivity analysis. Alternative scenarios included, relative to baseline parameters: (1) yield gains increase by 10%; (2) production cost per ton further reduced by 10%; (3) sorghum price increase of $50/ton; (4) discount rate increased from 5% to 10%; (5) discount rate increased from 5% to 25%.

An increase in the yield advantage, such as those predicted for newly released hybrids, has a dramatic impact on all summary measures of financial returns, other assumptions held constant. Net present value, benefit-cost ratios, and poverty reduction rates increase by multiples of ten, and the internal rate of return more than doubles.

Higher production costs, however, would dramatically reduce net present value, internal rate of return, benefit-cost ratios, and poverty impacts. Thus, cost effects associated with greater yield advantages would partially offset the overall benefits of productivity growth. Rising sorghum prices, such as those that have occurred since the global food price crisis, would also augment benefit streams. Overall price effects are relatively minor given that sorghum is a staple and both demand and supply are relatively inelastic. Higher discount rates to reflect risk and the financial perspectives of private as compared to public investments, have no effect on the internal rate of return of poverty reduction, but have sizeable effects on the net present value and benefit-cost ratios.

Clearly, the base model estimates based on the initial assumptions and targets of the pilot project are well within the range of possible benefits implied by alternative assumptions. The sensitivity analysis thus lends credence to the stability of benefits and returns under the baseline scenario.

A reference point for returns to sorghum and millet research is a meta-analysis of 22 studies conducted by Dalton and Zereyesus (2013). The authors found a global average rate of return of about 60% per year, with a wide dispersion. Higher estimates were explained by such factors as ex ante as compared to ex post analysis (ex post analyses generate lower, more realistic estimates), self- as compared to independent evaluation, and the assumption of a pivotal as compared to a parallel shift in the supply curve due to adoption.

As a global reference point for these preliminary estimates, in a comprehensive meta-analysis of rates of return to agricultural research and development reported in 292 studies, Alston et al. (2000) reported a median rate of return of 48.0% per year for research, 62.9% for extension studies, 37% for studies that estimated both the returns to research and extension, and 44.3% over all studies combined.

In the US, the Economic Research Service of the US Department of Agriculture analyzed findings from 26 studies that assessed the rate of return to public agricultural research in the United States over various periods of the 20th century. Estimated rates of return varied depending on study methodology and coverage, but most ranged from 20 to 60%.

6. CONCLUSIONS

Alongside millet, sorghum is one of the two main dryland cereals produced in Mali, and both a food staple and ready source of cash for the majority of the country's predominantly rural population. Raising sorghum productivity through development of higher-yielding varieties has been a policy priority for the Government of Mali and for ICRISAT since the Sahelian droughts of the 1970s-80s. ICRISAT's involvement in sorghum improvement in the Sahel dates to 1975.

Few studies have been published on the adoption and impacts of introducing improved sorghum varieties in Mali. Matlon (1990) estimated an adoption rate of only 5% for improved seed in the West African Sahel, referring to both exotic germplasm and the weakness of national research and extension systems as constraints. Yapi et al. (2000) documented farmers' preferences for selected, purified landraces as compared to crosses and selections from exotic germplasm. They estimated overall adoption rates of 30% in Segou, Mopti, and Koulikoro. Their findings laid part of the foundation for a directional change in Mali's sorghum improvement program. Since then, researchers at IER and ICRISAT have continued to work with exotic germplasm. However, they have also produced a range of improved materials, including sorghum hybrids, using local Guinea-race materials that are photo-period sensitive and have desirable grain and storage quality as well as better insect and Striga resistance. In addition, seed supply constraints related to the state-managed, formal system have led to other approaches to diffusing improved seed. The approach encouraged by ICRISAT's program in Mali is based on a decentralized, participatory approach to testing new materials and diffusing them among farmers.

The objective of this analysis has been to update the study by Yapi et al. (2000). We have synthesized earlier research on adoption and sorghum seed use in Mali. As part of this study, we have implemented a census of farmers in 58 villages in the Cercles of Dioila, Kati, and Koutiala, where new sorghum materials have been tested in farmers' fields through farmers' unions. We have also conducted an ex post assessment of returns to research investment.

Overall, the use rates reported here are similar to those reported by Yapi et al. (2000). However, the materials used by farmers are different today than at the time of their study. Yapi et al. (2000) analyzed use rates for purified landraces and exotic sorghum germplasm, while those we analyse in this study are all materials bred by the national program and ICRISAT, including the first Guinea-race hybrids. Thus, the fact that the percentage of sorghum area planted in new materials does not appear to have changed appreciably over the past few decades does not imply that advances have not been made in the use of improved seed. Changes in the composition of seed types (toward nationally-bred, Guinea race materials), seed acquisition practices (toward cash purchases), and women's roles in sorghum production appear to have been substantial. In fact, the relevant counterfactual would be *what would have happened if* variety turnover had not occurred. Variety turnover is crucial for maintaining host-plant resistance to evolving plant diseases and stresses. The large range of diverse, well-adapted materials released by the Malian program and planted in farmers' fields attests to the program's dynamism and stands in sharp contrast to other nations (e.g., Sudan) where the improved sorghum varieties that dominate in farmers' fields were bred over two decades ago (Timothy Dalton 2014[2]). Furthermore, as noted above, farmers often rename introduced materials with their own names once they have fully accepted them in their local varietal portfolio.

[2] Personal communication November 4, 2014.

The assumptions we have invoked in our baseline estimates of returns to research investment are conservative. Assuming only a 21% yield advantage and a ceiling adoption rate of 33% of national sorghum area, the rate of return to investment in sorghum improvement in Mali since 1997 is estimated at 25%, with six dollars earned for every dollar invested. Each year, on average, 20,000 persons are estimated to have crossed the $1 poverty line as a result of higher sorghum productivity. Increasing the yield advantage to 31%, with no change in other parameters, generates an internal rate of return of nearly 60% and a benefit-cost ratio of 63:1. Across a broad range of management conditions on farmers' fields, the estimated average yield advantage associated with newly released sorghum hybrids is 30%. These estimates compare favorably with the more conservative estimates generated in other global studies, and should be understood as a lower bound on our overall estimates of gains from Mali's sorghum improvement program.

ANNEXES

Annex A. Survey Instrument

SECTION 1: MEMBRES DE l'UPA | IDM | | | | |

Enqueteur: Posez Je voudrais vous poser des questions sur la composition de votre UPA aujourd'hui.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Id. No	Nom	Prenom	Quel est le sexe de [...]? 1=H 2=F	Quel est le lien de parenté de [...] avec le chef du ménage? (Liste A)	Quel âge [...] a-t-il(elle)?	Quel est le statut matrimonial de [...]? 1=marie(e) 2=divorce(3) 3=veuf(ve) 4=celibataire	L'hivernage derniere, d'un hivernage a l'autre, [...] a ete absent pendant combien de **jours**?	Quelle est la langue principale de la mere de [...]? 1=bambara 2=peulh 3=miyanka 4=senoufo 5=Autre à préciser :	Quelle est la langue principale du pere de [...]? 1=bambara 2=peulh 3=miyanka 4=senoufo 5=Autre à préciser :	Quelle est la langue principale de [...]? 1=bambara 2=peulh 3=miyanka 4=senoufo 5=Autre à préciser :	Cette personne participe-t-elle dans ces activites semencieres dans ce village? 1=tests de varietes 2=production de semences 3=ni l'un ni l'autre	Presentement, cette personne a-t-elle des responsabilites dans le village ? 1 = Oui 2 = Non >> Q19	Si oui, indiquez toutes celles qui lui sont appropriés (Liste D)	Auparavant, avez-vous eu des responsabilites dans le village ?1 = Oui 2 = Non	Si oui, indiquez toutes celles qui lui sont appropriés (Liste D)
1													[__][__][__]	[__][__][__]	
2													[__][__][__]	[__][__][__]	[__][__][__]
3													[__][__][__]	[__][__][__]	[__][__][__]
4													[__][__][__]	[__][__][__]	[__][__][__]
5													[__][__][__]	[__][__][__]	[__][__][__]
6													[__][__][__]	[__][__][__]	[__][__][__]
7													[__][__][__]	[__][__][__]	[__][__][__]
8													[__][__][__]	[__][__][__]	[__][__][__]
9													[__][__][__]	[__][__][__]	[__][__][__]
10													[__][__][__]	[__][__][__]	[__][__][__]
11													[__][__][__]	[__][__][__]	[__][__][__]
12													[__][__][__]	[__][__][__]	[__][__][__]
13													[__][__][__]	[__][__][__]	[__][__][__]
14													[__][__][__]	[__][__][__]	[__][__][__]

Liste A: Lien de Parenté par rapport au chef d'UPA

1=Chef d'UPA	11=Fils
2=Première épouse	12=Belle fille
3=Deuxième épouse	13=Fille
4=Troisième épouse	14=Petit fils
5=Quatrième épouse	15=Petite fille
6=Mère	16=Autre à spécifier
7=Frère	A:_______________
8=Soeur	B:_______________
9=Cousin	

Liste B: Responsabilites

1=conseille au chef du village

2=leader d'une cooperative ou association de producteurs

3=conseille municipale

4=responsabilites coutumieres

5=autres (a specifier): A.

SECTION 2: PARCELLES DE L'UPA

IDM [__|__|__|__|__|__|__]

Enquêteur: Demandez des informations sur chaque parcelle au responsable de la parcelle. S'il vous plaît enregistrez toutes les parcelles qui ont été cultivées ou détenus par les membres du ménage: Dites: Maintenant, je voudrais vous poser quelques questions sur les parcelles appartenant aux membres de l'UPA qui sont utilisées par les membres de l'UPA. Il s'agit non seulement de vos parcelles, mais aussi celles des autres membres de l'UPA ainsi que les parcelles louées par les membres de l'UPA.

	Quel est le membre de l'UPA qui gere cette parcelle?			4	5	6	7	8	9	10	11	12
ID de la parcelle	*1.PID*	*2.Nom*	*3. Prenom*	*Quel est le nom de la parcelle ou autre point de repere? (par example, bas-fonds, colline…sa situation)*	La parcelle a-t-elle été cultivée au cours du dernier hivernage?	Quelle est la taille de la parcelle? Taille *(hectare)*	Quelle est la source d'eau pour cette parcelle? (Liste A)	Quelle est la culture principale cultivée sur cette parcelle pendant l'hivernage? (Liste B)	Quelle est la culture principale cultivée sur cette parcelle pendant la contre-saison?	Quelle est la première culture associée sur cette parcelle? (Liste B)	Quelle est la deuxième culture associée sur cette parcelle? (Liste B)	Quel est le type de sol qui domine cette parcelle? (Liste C)
1					[___]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
2					[___]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
3					[___]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
4					[___]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
5					[___]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
6					[___]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
7					[___]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
8					[___]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
9					[___]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
10					[___]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
11					[___]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
12					[___]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
13					[___]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
14					[___]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
15					[___]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]
16					[___]			[__][__]	[__][__]	[__][__]	[__][__]	[__][__]

Liste A	
1=Sorgho	9=Courges
2=Mil	10=Calebasses
3=Mais	11=autres (specifier)
4=Riz	A. __________
5=Arachides	B.__________
6=Niebe	C. _________
7=Patates	
8=Ignames	

Liste B
1=Pluie
2=Puits
3=Forage
4=Irrigation à motopompe
5=Canal

Liste C	
1=Sableux	7=sab/grav
2=Limoneux	8=lim/arg
3=Argileux	9=lim/grav
4=Gravilloneux	10=arg/grav
5=sab/lim	
6=sab/arg	

SECTION 3: SEMENCES SORGHO

IDM [__|__|__|__|__|__]

Enquêteur: Demandez des informations au chef de travaux sur chaque ecotype ou variete de sorgho qui a ete introduit dans cette UPA dans les 5 dernieres annees.

1.	Quel membre de l'UPA a introduit cette variete?			5	6	Indiquez la superficie semee					La supercie semee de [……], a-t-elle accrue ou diminuee depuis l'introduction?		Sur quelles parcelles a-t-elle ete semee? (voir feuille 3)	
liste de toutes ecotypes ou varietes de sorgho semees de 2009-2013 (a decrire)	2.PID	3.Nom	4.Prenom	Achat, don ou echange la premiere fois semee? 1=achat minipack 2=autre achat 3=don 4=echange 5=lors d'une visite d'echange organisee	Source de semences (liens sociaux, Liste A)	7. 2013	8. 2012	9. 2011	10. 2010	11.2009	12. 1=accrue 2=diminuee	13. Pourquoi le changement	14. ID	15. Nom ou point de repere

Liste A
1=producteurs de semences
2=autre producteur, non-parente, meme village
3=autre producteur, non-parente, autre village
4=autre producteur, parente, meme village
5=autre producteur, parente, autre village
6=services de vulgarisation
7=union de producteurs
8=agro-dealers
9=boutique d'intrants
10=commercants
11=foires de semences
12=autres (a preciser)

Annex B. Data Used in Economic Surplus Model

B-1. Traditional Sorghum Variety Farm Budget

Items	Unit	Quantity	Unit cost	Value
Variable costs				
Labor				
- Field preparation	Man days	4	1,500	6,000
- Plowing	Man days	2	1,500	3,000
- Manure application	Man days	1	1,500	1,500
- Sowing	Man days	3	1,500	4,500
- Weeding1	Man days	6	1,500	9,000
- Weeding2	Man days	6	1,500	9,000
- Harvesting	Man days	8	1,500	12,000
- Threshing	Man days	5	1,500	7,500
- Hauling	Man days	3	1,500	4,500
Seeds	kg	10	100	1,000
Farm yard manure	ton	3	10,000	30,000
Insecticide	liter	0	600	0
Fertilizer	kg	0	250	0
Equipment rental	days	4	5,000	20,000
Total variable cost	CFA/ha			118,000
Output per Ha	Kg/ha			950
Unit variable cost	CFA/kg			125
Unit variable cost reduction	CFA/kg			-

Source: Authors.

B-2. Improved Sorghum Variety Farm Budget

Items	Unit	Quantity	Unit cost	Value
Variable costs				
Labor				
Field preparation	Man days	4	1,50	6,000
Plowing	Man days	2	1,50	3,000
Manure application	Man days	1	1,50	1,500
Sowing	Man days	3	1,50	4,500
Weeding1	Man days	6	1,50	9,000
Weeding2	Man days	6	1,50	9,000
Harvesting	Man days	8	1,50	12,000
Threshing	Man days	5	1,50	7,500
Hauling	Man days	3	1,50	4,500
Seeds	kg	8	400	3,200
Farm yard manure	ton	3	10,0	30,000
Insecticide	liter	2	600	1,200
Fertilizer	kg	150	250	37,500
Equipment rental	days	4	5,00	20,000
Total variable cost	CFA/ha			158,900
Output per Ha	Kg/ha			1,500
Unit variable cost	CFA/kg			105
Unit variable cost reduction	CFA/kg			20

Source: Authors.

B-3. Hybrid Sorghum Farm Budget

Items	Unit	Quantity	Unit cost	Value
Variable costs				
Labor				
- Field preparation	Man days	4	1,500	6,000
- Plowing	Man days	2	1,500	3,000
- Manure application	Man days	1	1,500	1,500
- Sowing	Man days	3	1,500	4,500
- Weeding1	Man days	6	1,500	9,000
- Weeding2	Man days	6	1,500	9,000
- Harvesting	Man days	8	1,500	12,000
- Threshing	Man days	5	1,500	7,500
- Hauling	Man days	3	1,500	4,500
Seeds	kg	8 4-5	800	6,400
Farm yard manure	ton	3	10,000	30,000
Insecticide, possibly	liter	2 none	600	1,200
Fertilizer	kg	150	250	37,500
Equipment rental	days	4	5,000	20,000
Total variable cost	CFA/ha			162,100
Output per Ha	Kg/ha			2,500
Unit variable cost	CFA/kg			65
Unit variable cost reduction	CFA/kg			60

Source: Authors.

B-4. Area, Production, and Prices of Sorghum in Mali

Year	Area (000'ha)	Production (000't)	Price (CFA)
2000/2001	674.768	564.662	59
2001/2002	702	517.748	93
2002/2003	923	641.848	134
2003/2004	822	727.632	94
2004/2005	577	664	63
2005/2006	744	629	121
2006/2007	917	769.681	91
2007/2008	1,090	900.791	83
2008/2009	990.995	1,027	100
2009/2010	1,091	1,465.620	118
2010/2011	1,225.928	1,256.806	111
2011/2012	1,685	1,191	124
2012/2013	1,245.569	1,212	188
2013/2014	1,295	1,260.937	129
2014/2015	1,347	1,311	133

Source: CPS-SDR 2014; OMA 2014.

B-5. Research and Extension Cost (in US Dollars) for Sorghum Improvement in Mali

Year	IER	ICRISAT	Extension	Total
2000/2001	35,000	0	0	35,000
2001/2002	35,000	0	20,000	55,000
2002/2003	40,000	105,000	20,000	165,000
2003/2004	40,000	107,000	20,000	167,000
2004/2005	40,000	109,000	30,000	179,000
2005/2006	50,000	111,000	30,000	191,000
2006/2007	50,000	150,000	30,000	230,000
2007/2008	50,000	200,000	35,000	285,000
2008/2009	50,000	226,133	35,000	311,133
2009/2010	50,000	226,133	40,000	316,133
2010/2011	40,000	226,133	40,000	306,133
2011/2012	30,000	226,133	40,000	296,133
2012/2013	20,000	226,133	40,000	286,133
2013/2014	0	150,000	30,000	180,000
2014/2015	0	100,000	25,000	125,000
2015/2016	0	0	20,000	20,000
2016/2017	0	0	10,000	10,000
2017/2018	0	0	0	0
2018/2019	0	0	0	0
2019/2020	0	0	0	0

Source: Authors.

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