Achieving sustainable cultivation of sorghum

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Introducing new technologies and market strategies for sorghum producers in developing countries: the Sahel case

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1 Introduction

The dilemma of raising yields for a crop produced principally for home consumption is that yields, input use and expected prices are all low but interrelated, requiring different strategies to change. Soils in semi-arid regions of sub-Saharan Africa are poor. This requires fertilizers which farmers cannot always afford. Low yields mean little surplus marketed so that the farmers deal with the lowest level of the marketing chain, sell at the depressed seasonal price right after harvest, typically selling a low-quality product with 10–20% impurities. Changing the marketing strategy requires increased storage capacity, better quality control and the ability to amass and sell larger quantities to higher levels of the marketing chain. This requires both improvements in technology and institutional change (e.g. farmers’ associations for cooperative marketing).
The secondary markets for sorghum will also become more important as with income growth, people will eat less cereal and more quality foods including poultry. So the conditions for sorghum to substitute for maize in the feed ration are also considered.

A final issue to consider is the need for research to respond to new problems as they arise. As an example, an improved variety proved ‘softer’ than local varieties and this required changing the processing of the local staple food ‘tô’ so that it retained the consistency required by consumers.

This chapter reports on the field research of a programme combining agronomic and economic components over the period 2004–16. The programme initially included four Sahelian countries and then focused on Mali as it moved from the pilot to the scaling-up process. Specifically, we are concerned with introducing new sorghum technologies and improving marketing strategies. Also a focus is needed on the development of an institution to facilitate this process and the ability to respond to evolving problems.

2 Sorghum performance and potential: Mali and Burkina Faso

Over the last decade, aggregate maize yields have doubled from 1.5 to 2.8 t/ha in Mali. Sorghum yields have stagnated, occasionally making it to one ton in good rainfall years but often remaining around 750 kg/ha (Fig. 1). In Burkina Faso, maize yields began the period lower than in Mali at 1.25 t/ha. Yields did not increase as much as in Mali reaching less than 2 t/ha (Fig. 2). With the introduction of Bt cotton in Burkina, returns to cotton have not fallen as much as in Mali so there has been less shift of farmer concentration to maize in the cotton zone (Coulibaly et al., 2015).

There are various reasons for the superior performance of maize as compared with sorghum in both countries. There has been a more rapid introduction of both improved

![Figure 1](maize_sorghum_yields.png) Maize and sorghum yields (t/ha) in Mali, 2006–14. Source: ADA (Directorate of National Agriculture), 2015.
maize cultivars and hybrids in both countries. Moreover, inorganic fertilizer use and more recently extensive use of fertilizer subsidies have favoured the yield and production increases for maize. There has been support from both IITA (International Institute for Technology in Africa) and CIMMYT (International Maize and Wheat Improvement Center) on introducing new maize cultivars and other improved technologies. Moreover, maize production is concentrated in the higher rainfall regions on better soils in a high input using region. In contrast, sorghum is found in most regions of both countries and is a very important cereal cultivar in lower rainfall and poorer soil fertility regions.

Considering production, maize went from 600,000 t to almost two million t over the decade, more than tripling in Mali (Fig. 3). In Burkina, maize production also tripled from 500,000 to 1.5 million t over the decade (Fig. 4). In Mali, sorghum production ranged from one million to 1.5 million t. Whereas in Burkina, sorghum production ranged from 1.5 million to almost two million t. So the big gains were with maize productivity, while sorghum productivity remained stagnant but increased area and weather had a large effect on the sorghum output.

Both sorghum and maize are used for the traditional food product in rural and, to a lesser extent, urban areas, ‘ tô’ a porridge with the consistency of ‘polenta’. ‘Tô’ is eaten with sauces of various types with the historic preference for most regions being the ‘ tô’ from millet. Sorghum is substituted for millet in poor weather as millet is produced on lighter, more marginal soils than sorghum. Also, sorghum ‘ tô’ is often preferred in regions where the predominance of heavier soils favours sorghum production. When other cereals such as maize with its high yields in the cotton–maize–sorghum systems, characterizing southern regions of Mali and Burkina Faso, become cheaper, they are substituted for the millet or sorghum in the ‘ tô’.

So, what is the potential for sorghum to increase yields? Sorghum yields in Mali and Burkina are compared with the historic performance of yield increases of sorghum and maize in the United States. Sorghum yields were tripled in the United States in less than 20 years (1955–72) from 1.25 to 3.5 t/ha (Miller and Kebede, 1987). Maize yield increases started slowly during the Depression but ultimately reached twice the sorghum yields by 1987 (Duvick, 1987).

Maize is grown on better soils with higher rainfall and generally higher input levels than those of sorghum. The basis of these yield increases for both cereals was improved

![Figure 2](image-url) Maize and sorghum yields (t/ha) in Burkina Faso, 2004–13. Source: Département d’Agriculture, 2015.

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cultivars, mainly hybrids, increasing fertilization, improved agronomic practices and some irrigation (Miller and Kebede, 1987; Duvick, 1987).

The bottom line is that maize has achieved much higher yields in both the Sahelian countries and in the United States. However, there is a very large yield gap between actual Malian and Burkina yields and potential sorghum yields as indicated by experiment station yields in Mali and Burkina or with the US historic yield performance of sorghum. Hence, there is a substantial potential to close this sorghum yield gap on farmers’ fields in Mali and Burkina.

Moreover, sorghum has an increasing comparative advantage as cereal production moves out of the prime agricultural regions into lower, more variable rainfall regions. Even in the high input using countries, as the United States, sorghum continues to be a principal cereal cultivar in the drier regions (western regions of Texas, Kansas and Nebraska).

So what needs to happen for new sorghum technology to become rapidly adopted by farmers?

Figure 3 Maize and sorghum production (t) in Mali, 2006–14. Source: ADA (Directorate of National Agriculture), 2015.

Figure 4 Maize and sorghum production (t) in Burkina Faso, 2004–13.
3 The strategy: breaking out of subsistence

With ‘subsistence’, crops farmers use few inputs and receive low prices. Yields are low and variable principally due to rainfall variability. Prices are low because farmers sell at the seasonal low point of prices shortly after the harvest (Fig. 5) and the buyers are at the lowest level of the marketing chain. Many collectors pick up at the farms or in the villages, so their costs, and hence margins, are high. Farmers want to sell at harvest as they have a seasonal demand for money at harvest. Pressing harvest time expenditures are school fees, weddings and naming ceremonies (equivalent to baptisms for Muslims), labour payments including presents for wives for their work in the field, deferred health and other pressing household expenses. Farmers also need to store cereals for home consumption during the year and to use small quantities of cereals as cash in exchange at the regular village or town markets.

Getting higher yields is not difficult with moderate levels of inorganic fertilizer, new cultivars responsive to fertilizer and improved agronomy. But it does require farmer training and the availability and purchase of improved seed and fertilizer (for the 2006–07 and 2007–08 crop years, see Abdoulaye et al. (2008) and Baquedano et al. (2009)).

The specific recommendations were initially two 50-kg sacks of NPK (15-15-15) and one sack of Urea (46-0-0) per ha. Improved, fertilizer-responsive cultivars that had been regionally tested were utilized. Agronomic improvements of use of organic fertilizer, water control with ridges or tied ridges, higher densities, thinning and appropriate timing of planting and weeding were recommended. Later the inorganic fertilizer recommendation

Figure 5 Sorghum prices in Koutiala retail markets, 2003–09. Source: Coulibaly et al., 2015, p. 55.
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was changed to one 50-kg sack of DAP (18-48-0) and one sack of urea per ha (manual of agronomic and economic recommendations in Ouendeba et al. (2013)). Comparing the two nutrient levels per ha, the three-sack treatment for above results in 38 kg/ha, 7.5 kg/ha and 7.5 kg/ha of N, P and K, respectively. Whereas the two-sack treatment of higher nutrient DAP combined with urea puts 32 kg/ha of N, 31.5 kg/ha of P and 7.5 kg/ha of K on farmers’ fields.

The technology and marketing strategy were followed in farmers’ associations organized or adapted for this purpose. Working in farmers’ associations also had the benefit of a more rapid diffusion process as farmers learned from other farmers who were successful. The adoption of this system can increase yields by 50–100% (for the 2008–09 and 2010–11 crop years, see Coulibaly (2010) and Coulibaly et al. (2013)).

The critical factors here are that the strategy needs to be profitable and to take risk into account. Focusing first on the risk many have argued for a low input strategy. Clearly, low-income farmers have multiple strategies to reduce risks. They plant on various areas of the topo-sequence (lowlands, slopes, plateau) to reduce the impacts of flooding and drought. They plant various crops and varieties to respond to rainfall variation and insect/disease risks. Family and friend networks are used by making interchanges so that there are contacts in the village and often in the city for help in adverse years. In good years the transfers as of cereals can go to the urban area and in adverse years, grain or money comes from the urban area to the farm.

Nevertheless, many farmers also understand the fundamental risk–return tradeoff: to earn more money it is generally necessary to take more risks. Farmers, like any entrepreneur, need to have the opportunity to make that choice but without putting their basic subsistence at risk. Reducing production risk in this system involves increasing water holding capacity with ridges or tied ridges (this is a technique practised in Africa and Texas of making ridges perpendicular to each other to hold the rainfall).

But there is another important response to risk by increasing returns with marketing innovations. The soils of semi-arid sub-Saharan Africa are notoriously deficient in N and P. Fertilizer is expensive, so many have recommended some types of low input strategies to reduce fertilizer expenditures. However, in dealing with human nutrition, should poor, malnourished people be asked to save money by reducing food expenditures? Similarly, with plants, adequate levels of N and P are essential to increase yields as long as methods can be found to pay for these inputs. This should first lead to a concern with product prices and marketing margins rather than reducing input use.

Working within a farmers’ association, the farmer can benefit from product price increases by storage and selling later after the price recovery, from obtaining a price premium by eliminating impurities (dirt, stones, other varieties, etc.) (Toure et al., 2007) and from selling to a higher level of the marketing chain (Abdoulaye and Sanders, 2006; Baquedano et al., 2010; Ndoye et al., 2016).

Farmers can continue to sell some of their sorghum for the required expenditures at harvest and the uses discussed earlier. However, with the higher yields from the new technology, farmers can sell part of the harvest later and to higher levels of the marketing chain.

As a member of a farmers’ association with storage facilities, the sale can be put off until the price has recovered or the farmer needs the cash for the inputs for the next production season (Fig. 5). However, over time, the farmers’ association must also respond to the processor demand. The processor needs the cereal year around. Assuming that the
farmers’ association can differentiate their product with a ‘clean’ sorghum, the buyer will need to pay a premium to buy early.

Food processors and higher levels of the marketing chain want a ‘clean cereal’ with very low impurities. So the harvesting operations cannot be done on the ground. Moreover, screens are often used at the farm or storage level. There was initially some struggle with processors to get this price premium. Over time, processors have been learning that this is not a zero sum game where if they win, you lose. Rather a long-term relationship is necessary with processors paying for a higher quality product which saves cleaning costs and gives 5–25% more cereal per bag (the levels of impurities from sampling of the cereals at five food processors purchased from eight markets in 2006, see Toure et al. (2007)). Maintaining clean cereal requires more work for farmers and for the farmers’ association to guarantee quality. As processors began to recognize their interdependence with suppliers to produce a quality product, the resistance to a price premium in meetings with processors declined and the price premiums they paid began creeping up (field experience in this programme from Senegal and Mali).

In the traditional marketing system (Fig. 6) there are several levels with each earning its own margins. The collector with financing from a regional merchant or wholesaler visits farms at harvest and goes to the village markets later in the year aggregating small quantities. Then the regional merchant sells to the wholesaler either locally or in a major urban area. The wholesaler sells to processors or retailers. Recent additions are the farmers’ associations performing the collection and regional merchant functions.

Normally with low yields of poor rainfall years there is little sold even though collectors are offering better prices than in the good rainfall year with abundant supply. The agronomic system with both organic and inorganic fertilizers holds water as well as increases soil fertility thus increasing yields over traditional farmers’ practices in poor rainfall years. The yield gains are not as great as in normal and good rainfall years but it is exactly in these poor rainfall years that there is the largest seasonal price increase (Fig. 5).

Besides the timing of the sales the farmers’ association also seeks the marketing margins previously received by the lower levels of the marketing chain. A problem frequently occurs as the marketing system resists change. Marketing systems are often ‘old boy’ networks with personal contacts between levels. So the farmers’ associations need to anticipate the potential of cartels between wholesalers or even regionally to avoid changes or to enable the wholesaler to capture the previous margins of the lower levels of the marketing chain, the collectors and the regional merchant. This may require farmers’ associations to go outside the regional cartel (arbitrage) as to the urban wholesalers or to processors. More marketing power is possible from the collaboration of farmers’ associations to market larger quantities. Often the threat of selling outside the region will be sufficient to obtain a larger share of the marketing margin for farmers’ associations.

To summarize, as members in a farmers’ association, farmers often have access to storage and can wait for the price recovery. Moreover, by selling a clean, uniform cereal, farmers can demand a higher price. Finally, the farmers’ association, by selling larger quantities, can skip stages in the marketing chain by selling directly to either processors or to wholesalers. Just as getting the processors to recognize that a higher price for cereals with reduced impurities did not necessarily mean a higher price for the cereal, the wholesalers and processors can get accustomed to paying higher margins to the farmers’ associations rather than to the collectors and regional merchants.
From different combinations of these activities farmers were able to increase prices by 30–50% (Abdoulaye et al., 2008; Baquedano et al., 2009; Coulibaly, 2010; Coulibaly et al., 2013). This is still considered a poor performance in obtaining price premiums for quality and identifying potential buyers; hence even larger price increases are expected as the negotiating and marketing abilities of the farmers’ associations are improved. Moreover, the total revenue of the farmers will increase as they entrust more of their cereals for sale by the association.

4 Pilot project success and scaling-up

In 2007 an especially high-yielding cultivar, Grinkan, was identified (see Fig 7). In 2008 and 2009 average yields from Grinkan in the Garasso, Mali farmers’ association were 1.56 t/ha and 1.94 t/ha (our informal field interviews in the farmers’ association with 50 members in
2008 and 135 members in 2009; Coulibaly reported yields of 1.64 t/ha for 2008; Coulibaly et al., 2015). Sorghum yields in the cotton rotation during this period were 800 kg/ha to 1 t/ha with sorghum often following the highly fertilized cotton in the rotation. This success was the incentive for the USAID-Mali programme to ask one of their agencies (IICEM) specialized in financing and facilitating new technology introduction of minor export crops to undertake the scaling-up of this pilot project.

In the movement from a pilot project to national scale, financing and management become critical constraints. In the pilot there was financing from the project and intensive management (mentoring, financing of inputs, marketing and storage advice). The pilot project financing had to be reimbursed to the farmers’ association creating a revolving fund for buying inputs at the start of each crop season. Farmers had to pay for their inputs. Hence, there was no direct subsidy to these programmes. However, there was intensive management for training and monitoring in the pilot project. Since this would not be available as the project scales up to national levels, this was an important indirect subsidy to the pilot project.

As the project moved from experimental to operational phase, the size increased substantially. In the Mopti region1, the project area increased from approximately 300 ha in 2009 (six farmers’ associations) to over 2000 ha with IICEM scaling-up in 2010. With the guarantee of the USAID project by depositing 50% of the loan value in case of default, the national development bank (BNDA) issued loans to the farmers’ associations for the fertilizer purchases. The BNDA did not finance the seed purchase but IICEM did facilitate the farmers’ associations in obtaining the seed. In the programme in the north (Mopti), there was

Figure 7 Farmer and NGO agent with Grinkan in Koutiala, Mali. 2008.

1. In the south of Mali, the sorghum variety Grinkan was introduced. In the north (Mopti), the millet cultivar Toroniou was adopted. The rest of the technology and marketing programs were the same. Reporting here on the scaling-up of millet is emphasized as more information was available on this process.
more emphasis on obtaining the variety recommended in the pilot. In the south (Koutiala), this was not the case. However, with regard to IICEM, Grinkan, a soft variety compared with the hard locals had more insect problems in storage. Moreover, the late season rains in 2009 and 2010 made seed quality a problem in the following season given the absence of drying equipment. Both problems could have been resolved if identified earlier. However, obtaining adequate good quality seed will always be a priority in scaling-up rapidly.

With good project management and high repayment rates the guarantee was reduced to one-third the value of the loans in 2011 and was eliminated in 2012. Unfortunately, the programme was disrupted by the war in 2012. When the war in the north forced the banks to close there, USAID-Mali provided financing directly to the farmers’ associations in Mopti. USAID-Mali followed the same procedure as that in our pilot project with the farmers required to reimburse the farmers’ associations in grain for the credit after the harvest. As of 2016, this financing was still available in the rotating funds of these farmers’ organizations. In some regions of the south, the Dutch government provided similar financing with the difference that only half of the funding was required to be repaid.

To give the BNDA more confidence that there were markets for the cereal, IICEM organized contracts between wholesalers and the farmers’ associations. The wholesalers pushed for the farmers’ associations to sell earlier and to sell more than sufficient to repay the loans. The agreed price was the market price at the time of sale plus a price premium for quality. Since the price varies during the crop season and the price premium for quality was lower than the expected value of the additional cereal available when impurities are removed, the farmers realized the disadvantages of selling either early or more to the wholesaler. Many found ways to avoid both. Nevertheless, the scaling-up was very efficient for furthering the recognition of the importance of the clean cereal, for involving the financial sector and for engaging with higher levels of the marketing chain.

The scaling-up of IICEM also handled well the management problem as the field workers were very active in mentoring the farmers especially stressing the importance of repaying the bank loans. The chronic problem of technology erosion was encountered. As a programme rapidly expands moving to the national level, shortcuts are often taken leading to either lower yields or higher costs or both. This can be due to difficulties of input supply, management time or just the desire of programme administrators to take decisions.

In both the Koutiala region for Grinkan and the Mopti region for Toroniou, the fertilizer recommendations in the scaling-up were frequently not observed and there was insufficient emphasis on seed renewal. As a consequence there were yield declines of 15–20% from the pilot (our field interviews). So the pilot project activity was continued in order to document the importance of getting the input levels right in the scaling-up.

In the second year of the pilot programme in the cotton zone of Burkina Faso, excellent yields for Grinkan were also obtained (Fig. 8) but here the problem of the processing preparation occurred even sooner than in Mali. In the next section, the response to this second-generation problem is explained.

5 Second-generation problems

Since agriculture is a biological system there are continuous changes going on. Often new technology systems will need to respond to these changes. Moreover, breeders or other
technology developers are not able to anticipate all the possible requirements of the biological system. Hence, it is important for continuing innovation to respond to evolving or unanticipated problems once a successful technology is identified.

This poses a financial problem in developing countries. Generally, the research and extension systems concentrate their expenditures on personnel and depend for operational expenditures on donors and non-governmental organizations (NGOs). So as one project terminates, the national organizations look for new projects and funders and switch their orientation. Who will respond to the emerging technology problems of the previous donor/NGO?

Later there were problems with Grinkan. First, with a softer grain Grinkan was very susceptible to insects in storage. Secondly, women accustomed to the preparation of their ‘ tô ’ by soaking overnight did not like the consistency (lack of stickiness) of Grinkan. The insect problem for sale can be handled with PIC (triple plastic sacks which become anaerobic when sealed) sacks or with Phostoxin and polyethylene sacks. The latter is generally preferred for long term seed storage.

The sorghum cultivar Grinkan got off to a fast start in adoption and marketing in Mali until women stated that they did not appreciate the consistency for their principal staple food from it, the ‘ tô ’. The women refused to buy Grinkan in the village markets. This led to the spreading upscale to the larger markets and the demand for Grinkan disappeared. A few farmers continued to produce Grinkan for their own consumption or for their animals.

Figure 8 Grinkan in Kouakole, Burkina Faso in 2012 with pilot program co-director B. Ouendeba, extension agent and a farmer.
The solution to the processing problem was easy. It was pointed out by a food scientist, Ababacar Ndoye (Sanders et al., 2016) and was discovered independently by some village women. With the soft cultivars such as Grinkan, women needed to avoid the overnight soaking. After adopting this procedure village women reported that they appreciated Grinkan more than their local cultivars (informal conversations in the villages making this adjustment).

Besides the second-generation problems, technology erosion in scaling-up is a continuing problem. So some independent financing to support research and extension over time is important to maintain technology introduction momentum. The dependence for operational funding on outside agencies with different priorities and programmes makes this investment response difficult.

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Figure 9 Improved sorghum/millet market structure with strong farmers’ associations producing large quantities of clean cereal. Source: Our projections based upon our fieldwork of 2015–16. See Ndoye et al., 2016, p. 104. There is a separate urban retail market where consumers buy the cereal in the market and have it dehulled and milled in local facilities. These facilities often use old equipment leaving metal residues. As costs are reduced in this system and there is more awareness of the health risks of this neighborhood processing, this neighbor milling is expected to decline.
Even though sorghum has an advantage over maize in its drought resistance, the deficit and variability of rainfall are continuing concerns in the sorghum-producing regions. However, over this period, excess rainfall causing flooding or occurring in later stages of the crop cycle had more significant negative effects than the rainfall deficits. The seed quality problem from late rainfall in 2010 and 2011 in the absence of drying equipment put an abrupt halt to the rapid expansion of Grinkan in Garasso, where the dramatic yield and production increases of the pilot project had convinced USAID to finance the scaling-up in 2010 (Coulibaly et al., 2015).

To summarize, when the project was scaled up beginning in 2010, area covered was 2000–3000 ha in both regions. The scaling-up programme worked well in the north (Mopti region) where pilot project recommendations were well observed. Even during the war in the north when the banks were closed down, the project was continued with USAID in the north and Dutch grants in the south to finance the revolving funds for the fertilizer purchases of the farmers’ associations.

As discussed earlier IICEM had problems in obtaining sufficient quantities of quality Grinkan seed and in observing the fertilizer recommendations of the pilot. But in 2016 Grinkan was still being produced in the region following the pilot recommendations in those villages where the farmers’ associations had modified the processing techniques. Another 17 farmers’ associations were shown in 2016 how to do this processing and given flash drives of the villages already modifying their processing operations

6 Institutional innovation: farmers’ associations as a marketing cooperative

The initial involvement with the farmers’ associations was to accelerate diffusion. Farmers tend to follow other farmers and do so at different speeds. They discount outside...
‘expert’ recommendations or even demonstration trials. So, the strategy was to convince approximately 50 farmers in a village association, either new or presently oriented to another crop, to follow the technology recommendations. These recommendations were based upon experience and interactions with the national research organizations over two decades. Credit was provided for the fertilizer to be reimbursed to the farmers’ organization. Not all the farmers were expected to follow the recommendations well the first year. But they were expected to follow the best farmers adopting the practices after the first year.

As long as the farmers were happy with the new cultivar this strategy worked very well. In the second year, 50 other farmers were recruited to the programme. The second group would get credit from the programme, while the first group would use the revolving fund. With higher prices being received, the revolving fund tended to increase so they could expand participants or use this for other purposes after providing the fertilizer credits to the first group. A similar process recruiting 50 new members in the third year and new credits was followed and then the programme for this village was ended. This was considered the ideal size for the village and programme. A revolving fund, storage facilities and management experience with both the technology and the marketing would have been built up by then.

The most important function for the farmers’ association was to provide the infrastructure, to assure larger quantities marketed and inputs purchased and provide management for the marketing activities. The association needed storage facilities to enable farmers to sell later especially in poor rainfall years when there were the largest seasonal price increases. The farmers’ association needed good management so that farmers trusted them to reimburse the farmers for the marketing gains. Also as the ‘clean cereal’ and larger quantity sales were components of the marketing strategy, a central control of quality and a management ability to identify and contract the best buyers became important. Larger quantities marketed meant that the farmers’ associations could deal with higher levels of the marketing chain, the wholesalers or the processors. Moreover, as the number of fertilizers and seed distributors increases, the farmers’ associations should be able to get price discounts for quantity purchases.

The marketing chain in the Koutiala region where Grinkan was concentrated is already moving to a new market chain system (Fig. 9). Here regional wholesalers are buying directly from farmers’ associations, while there continues to be smaller purchases later in the year in villages on market days. In the future the functions of the collectors and regional merchants will be largely eliminated as the farmers’ associations expand storage capacity, improve quality control and develop the ability to identify the best buyers. Then the farmers’ associations will become larger and even buy clean cereal from non-members.

Some farmers’ associations were selling directly to processors but they will need to guarantee quality to continue that. In one village farmers were doing further processing (flour), which could enable them to deal directly with retailers. Another future role, as management experience is increased, is to use the bank accounts of the farmers’ associations, in which the revolving funds are held as leverage to obtain bank lending for other activities of the farmers’ organization such as holding the cereal until the ‘soudure’ or hungry period (the months immediately before the availability of the next harvest).
7 Growth of a secondary market for sorghum

As incomes increase, people consume less grains and tubers and more fruits, vegetables, meat, milk and cheese. One of the principal beneficiaries of these consumption shifts is the intensive production of chicken. Substantial increases in production and consumption are experienced over two to three decades as producers get more efficient at reducing the cost of chicken relative to other meats. So there will be a rapid increase in the demand for feed grains over the next decade. Cereals represent 50–60% of the poultry feed by quantity depending upon the growth stage (Clement et al., 2010; Dowling et al., 2002; Tandliang et al., 2014).

Over the past two decades there have been very large increases in production and productivity (yields) of maize enabling a rapid growth of the poultry industry in both Burkina Faso and Mali. In both countries, the maize production is concentrated in the higher rainfall cotton zone, with 80% of the production in Mali (Mali Best Report, 2015). As the demand for feed increases for the intensive production of poultry, sorghum will have a comparative advantage over maize in the lower and more variable rainfall zones which are north of the cotton zones.

Most poultry producers and their veterinarians or other advisers for feed composition were not aware that sorghums without tannin were available and were approximately equal in feed efficiency to maize (field interviews; Sanders et al., 2016). Hancock has estimated that non-tannin sorghum has 95–97% of the feed efficiency of maize (Hancock conversation, autumn 2015; for more details on comparative feeding of maize or sorghum, see Hancock (2000), Clement et al. (2010), Carmencita et al. (2006), Dowling et al. (2002) and Tandliang et al. (2014)). This implies that with a relative price of sorghum to maize of 0.95, the chicken producers should be indifferent between maize and sorghum and would prefer sorghum at a relative price below 0.95.

So what do the relative prices show? In mid-2008 (Fig. 10) with the sudden increase in maize for biofuel in the United States and the world spike in agricultural prices, there was a brief period in which chicken producers had an incentive to switch. The chicken producers or their veterinarians responsible for the feed composition have to know about the potential of sorghum to substitute, know the relative prices and even more importantly know where to obtain uniform, non-tannin sorghum. Generally, the feed advisers for the poultry producers were not aware of the potential of non-tannin sorghum (field interviews in Mali and Burkina Faso, 2015 and 2016).

Since 2009 the more rapid gains in productivity of maize as compared with sorghum (Figs. 1 and 2) is an explanation for the decline of the substitutability of sorghum with the jump in the relative prices. Also during some of these years there were prohibitions on the export of maize. To the extent these were effective, they reduced the price of maize.

On the high sorghum prices, there are two rainfall effects. In poor rainfall years, millet suffers more on the light soils and then sorghum is needed to substitute for food. Then, millet and sorghum prices increase. In high rainfall years or even periods, sorghum suffers more as it is found on lower lying, heavier soils than millet; hence sorghum supplies are reduced and prices can increase.

In the future (next five years) there will be a definite advantage to sorghum over maize as larger quantities of the cereals are needed for feed and more will need to come from north of the cotton zone (lower rainfall regions). Moreover, sorghum is grown widely in
Mali and hence will not need to match the yield levels of maize for the relative price to decrease. Moderate yield increases of 0.5–1 t/ha over a wide area are expected to be sufficient (see Sanders et al. (2016)). Also there is the human and poultry health factor of maize being more susceptible to fungi in the field than sorghum. This includes the fungus-producing aflatoxin and this could explain the occurrence of sudden chicken deaths reported in field interviews with poultry producers in both Burkina and Mali (Sanders et al., 2016). Both sorghum and maize can experience fungi problems in storage and transportation.

Prospects are good for the increased utilization of sorghum in the poultry ration for two reasons. First, there is a larger yield gap for sorghum than for maize between the experiment station and the present national yields. Secondly, there are many competitive activities in the cotton zone and Bt cotton will enable a comeback of cotton in Mali as it has in Burkina Faso (Baffles, 2011; Coulibaly et al., 2015). This will at least partially reverse the shift to maize that has occurred with falling cotton prices (Coulibaly et al., 2015). Consequently, in the next decade, cereal productivity for feed which is north of the cotton zone will become increasingly important to the poultry industry as well as improving income distribution in the Sahel. This movement north of the increasing cereal supply for poultry feed would favour sorghum over maize.

8 Conclusion

There is substantial potential for yield increases of sorghum in Mali and Burkina Faso. Sorghum is very important not only as a basic staple food, especially when millet yields are poor, but also to support the rapidly expanding poultry industry. The continuing demand growth for feed will require the expansion of cereal production especially outside of the cotton zones.

Increasing cereal yields is well known as resulting first from soil fertility amendments and then adding in varieties (or hybrids) that are fertilizer-responsive, and finally accompanying agronomic inputs. So why has this not been done with sorghum and millet? Unfortunately, low-input concepts have often focused attention on reducing the input costs of these ‘subsistence’ crops. A more appropriate strategy is to pay for these necessary inputs to increase soil fertility with marketing changes to increase product prices received by farmers (as well as with the economic gains to the new technologies).

With the introduction or expansion of existing farmers’ organizations, farmers can benefit from storage and price recovery after the harvest season’s price collapse; obtain a price premium from the value added of selling a ‘clean’, uniform cereal and deal directly with higher levels of the marketing chain. Selling directly to wholesalers gives the farmers’ organization the potential to capture the marketing margins of collectors and regional merchants. Moreover, a farmers’ organization can achieve more market power by dealing in larger quantities with both the cereal sales and the purchase of inputs.

Since the 1970s, there have been substantial investments in the agricultural research systems of developing countries. These national agricultural research institutions have become increasingly competent at identifying, adapting and developing new cultivars.
and associated technologies. However, there has often been disappointment about the pace at which these technologies are incorporated by farmers and adopted over large areas. Generally, the research stations argue that this diffusion is the responsibility of the extension service once on-farm or regional trials have been undertaken.

There has not been as much investment in the training and functioning of the national extension services and they have often not fully perceived what the researchers were trying to do and opted to concentrate on encouraging best farmer diffusion rather than accelerating new technology adoption of innovations from the experiment station. Moreover, both national research and extension systems frequently suffer from insufficient operating budgets.

With their budgets focused on paying personnel, both the research and extension, institutions then become dependent upon outside donors and NGOs for operating funds. These NGOs and donors have shifting objectives over time. Since agriculture is a continually evolving biological system, new problems evolve over time or were there already but not identified by the technology developers. Resources need to be found to maintain the gains to innovation as these constraints are identified or new constraints emerge.

Moreover, the scientific and applied issues in moving from the station to the farm and then to the consumer tend to fall between disciplines so they become neglected. This is especially serious for those commodities, which according to conventional wisdom are ‘subsistence’ crops. Marketing systems and adaptation to consumer requirements are as important to facilitate introduction as the technology practices resulting in the need for the agricultural scientists, food scientists and marketing economists to collaborate.

9 Where to look for further information

On the introduction of hybrid maize and sorghum in the U.S., see Duvick, 1987 and Miller and Kebede, 1987 respectively.

For more information on the project and policy implications and after the data of 2008–2012 reported in section 10, see Abdoulaye and Sanders, 2006; Abdoulaye et al., 2006, 2007, 2008; Ibrahim, 2012, 2014.

For a summary article incorporating sustainability concerns into research and development activities, see Lynam and Herdit, 1989.

10 Appendix: associations and farmer details, 2008–12

Here is a partial listing of associations and estimates of farmers’ participation in the pilot projects (Tables A1 and A2). The associations were pressed, not always successfully, to have one farm family per ha so the approximate number of farmers can be easily calculated from the area data. More complete data on area for the period 2005–16 is available by contacting the principal author.
### Table A1 Sorghum area (ha) in the program, Mali 2008–12

<table>
<thead>
<tr>
<th>Project sites</th>
<th>Regions (Segou and Koutiala)</th>
<th>Improved sorghum varieties</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kafara</td>
<td>Koulikoro</td>
<td>Wassa, Nieta</td>
<td>50</td>
<td>50</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>100</td>
</tr>
<tr>
<td>Diola</td>
<td>Koulikoro</td>
<td>Soumba, Niaticham, Grinkan</td>
<td>76</td>
<td>96</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>172</td>
</tr>
<tr>
<td>Garasso, Koutiala</td>
<td>Sikasso</td>
<td>Grinkan</td>
<td>50</td>
<td>150</td>
<td>117</td>
<td>na</td>
<td>na</td>
<td>317</td>
</tr>
<tr>
<td>Kaniko, Koutiala</td>
<td>Sikasso</td>
<td>Niaticham, Grinkan</td>
<td>58.5</td>
<td>50</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>108.5</td>
</tr>
<tr>
<td>Zanzoni, Koutiala</td>
<td>Sikasso</td>
<td>Niaticham&lt;sup&gt;b&lt;/sup&gt;</td>
<td>–</td>
<td>50</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>50</td>
</tr>
<tr>
<td>Finkoloni, Koutiala</td>
<td>Sikasso</td>
<td>Niaticham</td>
<td>50</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>50</td>
</tr>
<tr>
<td>Seed Production Koutiala</td>
<td>Sikasso</td>
<td>Grinkan</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>540</td>
</tr>
<tr>
<td>Extension, Koutiala</td>
<td>Sikasso</td>
<td>Grinkan</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>530</td>
</tr>
<tr>
<td>Kolokani</td>
<td>Koulikoro</td>
<td>Seguifa</td>
<td>50</td>
<td>110</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>460</td>
</tr>
<tr>
<td>Diankounte Camara</td>
<td>Kayes</td>
<td>Seguifa</td>
<td>–</td>
<td>50</td>
<td>75</td>
<td>na</td>
<td>na</td>
<td>125</td>
</tr>
<tr>
<td>Katiëna</td>
<td>Segou</td>
<td>Seguifa</td>
<td>–</td>
<td>50</td>
<td>100</td>
<td>100&lt;sup&gt;a&lt;/sup&gt;</td>
<td>100&lt;sup&gt;a&lt;/sup&gt;</td>
<td>350</td>
</tr>
<tr>
<td>Beleco</td>
<td>Koulikoro</td>
<td>Tiandougou</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>60&lt;sup&gt;a&lt;/sup&gt;</td>
<td>60&lt;sup&gt;a&lt;/sup&gt;</td>
<td>120</td>
</tr>
<tr>
<td>Kita</td>
<td>Kayes</td>
<td>Tiandougou coura</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>60&lt;sup&gt;a&lt;/sup&gt;</td>
<td>60&lt;sup&gt;a&lt;/sup&gt;</td>
<td>120</td>
</tr>
<tr>
<td>Sadiola</td>
<td>Kayes</td>
<td>Tiandougou</td>
<td>–</td>
<td>–</td>
<td>50</td>
<td>na</td>
<td>na</td>
<td>50</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>334.5</td>
<td>606</td>
<td>442</td>
<td>340</td>
<td>850</td>
<td>2572.5</td>
</tr>
</tbody>
</table>

Source: Adapted from Diourte, 2012. More recent data available from the authors.

<sup>n.a.</sup>: Not available as either the village had graduated or for some reason as accessibility the project did not revisit.

<sup>a</sup>: Same technology and marketing program but managed by IER.

<sup>b</sup>: After promising to sell Grinkan to the neighboring villages one village sold the taller and inferior Nachtichama.

<sup>c</sup>: This is the number of farmers in the region receiving the program we were concentrating on when AIID took over the technology and marketing activity. The modifications AIID made are discussed in the text.

### Table A2 Millet area in the program, 2008–12

<table>
<thead>
<tr>
<th>Communes (Mopti region)</th>
<th>Villages</th>
<th>Number of storage units supported</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petaka</td>
<td>Oualo</td>
<td>2</td>
<td>60</td>
<td>120</td>
<td>180</td>
<td>180</td>
<td>180</td>
<td>540</td>
</tr>
<tr>
<td>Kanibonzon</td>
<td>Kanikombolé</td>
<td>1</td>
<td>–</td>
<td>60</td>
<td>80</td>
<td>20</td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>Sadi</td>
<td>–</td>
<td>1</td>
<td>–</td>
<td>60</td>
<td>80</td>
<td>120</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td>Koro</td>
<td>Téré</td>
<td>1</td>
<td>–</td>
<td>60</td>
<td>80</td>
<td>120</td>
<td>260</td>
<td></td>
</tr>
<tr>
<td>Komoro-Nah</td>
<td>Kountogoro</td>
<td>2</td>
<td>–</td>
<td>60</td>
<td>120</td>
<td>180</td>
<td>360</td>
<td></td>
</tr>
<tr>
<td>Pel</td>
<td>Témégolo</td>
<td>1</td>
<td>–</td>
<td>60</td>
<td>120</td>
<td>180</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Petaka</td>
<td>Pissa</td>
<td>0</td>
<td>60</td>
<td>60</td>
<td>na</td>
<td>na</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>Mougui</td>
<td></td>
<td>0</td>
<td>60</td>
<td>na</td>
<td>na</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Segou</td>
<td>Tingonih&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1</td>
<td>120</td>
<td>150</td>
<td>120</td>
<td>120</td>
<td>630</td>
<td></td>
</tr>
</tbody>
</table>

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### References


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#### Table: Communes Villages and Areas

<table>
<thead>
<tr>
<th>Communes (Mopti region)</th>
<th>Villages</th>
<th>Number of storage units supported</th>
<th>Areas (ha)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2008</td>
<td>2009</td>
<td>2010</td>
</tr>
<tr>
<td>Segou-Global</td>
<td></td>
<td>494a</td>
<td>500b</td>
<td>na</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>10</td>
<td>120</td>
<td>270</td>
</tr>
</tbody>
</table>

Source: Adapted from Diourte (2012).

n.a.: Not available as either the village had graduated or for some reason as accessibility the project did not return.

* Includes the program accelerating our program introduction in the same region and implemented by the AID funded IICEM (Economic Growth unit within USAID program). Note the guerrilla invasion of the north in 2012 and the comments in the text on how USAID continued program activities in that year with loans to the farmers for fertilizer to be repaid to the farmers’ associations at harvest in grain to set up a rotating fund for purchasing fertilizer in subsequent crop years.

b Tingoni is the name of the millet variety used in all the villages. This was used here to indicate the regional effect as IICEM reported 494 and 500 ha in this cultivar in 2010 and 2011 before the guerrilla attack in 2012. The column above was the project activity, which continued with the AID support.
Introducing new technologies and market strategies for sorghum producers


Ouendeba, B., T. Niaba and J. H. Sanders, 2013. Fiche de Production et de Commercialisation de Sorgho Grinkan, Production-Marketing Project of INTSORMIL. Department of Agricultural Economics, Purdue University, West Lafayette, IN 47907, 8p.

