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Analysis of the Economic Impact of Sorghum and Millet Research in Mali

International Crops Research Institute for the Semi-Arid Tropics

Abstract

Sorghum (*Sorghum bicolor* (L.) Moench) and pearl millet [*Pennisetum glaucum*] are very important to the economy and people of Mali. But, their productivity is low given the reliance on traditional, low-input production practices. The Institut d'Economie Rurale (IER) was started soon after the country's independence to find ways of improving the productivity of food crops in collaboration with regional and international agricultural research institutes (e.g., IRAT, ICRISAT, CIRAD-CA). A number of improved seed-based sorghum and millet technologies have since been developed and diffused. They were developed from two approaches: (1) selection within local germplasm, which consisted of collecting, testing, purifying, and supplying farmers with readily available materials. These are identified as Generation 1 materials; and (2) plant breeding, which consisted of crossing with exotic germplasm, and pedigree selection. Outputs of this second approach are identified as Generation 2 materials. This study evaluates the returns to sorghum and pearl millet research investments in Mali by combining farm-level survey information from 1990 to 1995 with that from research and extension in an economic surplus framework. The results indicate that by 1995, 30% of the sorghum and 37% of the millet areas were sown to improved varieties. The estimated benefits from research and extension efforts range from US$ 16 million (for sorghum) to US$ 25 million (for pearl millet). These represent internal rates of returns of 69% and 50%, respectively. A disaggregated analysis indicates higher yield gains and higher returns to Generation 2 materials than to Generation 1 materials for both sorghum and pearl millet. Unit costs were also much lower for Generation 2 materials. The major constraints cited by farmers as limiting their ability to adopt improved materials include lack of information, lack of improved seeds, and low soil fertility. The study concludes that the breeding philosophy should be diversified to respond to the need of the changing socioeconomic environment with the recent devaluation of the CFA. It also recommends that efforts be made to improve the economic farming environment to enable farmers to adopt more productive agricultural technologies which are necessary for rural poverty alleviation and improvement in national food security.

Résumé

Analyse de l'impact économique de la recherche sur le sorgho et sur le mil au Mali. **Les cultures de sorgho (Sorghum bicolor (L.) Moench) et de mil (Penisetum glaucum) ont une importance particulière pour l'économie et la population du Mali. Mais, leur productivité est faible en raison des pratiques traditionnelles impliquant l'application de peu d'intrants. L'Institut d'Economie Rurale (IER) a été créé bientôt après l'indépendance du pays afin de trouver des moyens pour améliorer la productivité des cultures vivrières en collaboration avec des instituts de recherche agricole régionaux et internationaux (IRAT, ICRISAT, CIRAD-CA). Depuis, de nombreuses nouvelles technologies basées sur les semences de sorgho et de mil ont été mises au point et diffusées. Elles reposent sur deux approches (1) Sélection parmi le germplasm local qui consiste à collectionner, à évaluer, à purifier et à fournir des matériels tout prêts aux paysans. Ce sont des matériels appartenant à la «génération 1» (2) Sélection végétale consistant à effectuer des croisements avec du germplasm exotique pour la sélection des lignées améliorées (pedigrees). Les produits de cette deuxième approche sont identifiés comme des matériels de la «génération 2». La présente étude évalue les rendements sur les investissements dans la recherche sur le sorgho et le mil au Mali en regroupant les informations obtenues au niveau des exploitations entre 1990 et 1995 avec celles provenant des activités de recherche et de vulgarisation menées dans un cadre de surplus économique. Les résultats indiquent qu'avant 1995, sur une superficie totale de culture, 30% a été allouée pour les semences du sorgho amélioré et 37% pour celles du mil amélioré. Les bénéfices résultant de ces activités de recherches et de vulgarisation sont estimés à 16 millions de dollars (pour le sorgho) et de 25 millions de dollars (pour le mil). Ils représentent des taux internes de rendements de 69% et de 50% respectivement. Une analyse plus détaillée indique que les matériels de la génération 2 ont eu des rendements et des bénéfices plus élevés que ceux de la génération 1 dans les deux cas du sorgho et du mil. Les prix d'unité étaient également plus bas pour les matériels de la génération 2. Les contraintes majeures pour l'adoption des matériels améliorés, selon les paysans, sont le manque d'information, le manque de semences améliorées and la faible fertilité du sol. En conclusion, la présente étude suggère que la philosophie de sélection doit être diversifiée pour répondre aux nouveaux besoins de l'environnement socio-économique suite à la dévaluation récente du franc CFA. Elle recommande également que des efforts soit faits pour améliorer l'environnement d'exploitation pour permettre aux paysans d'adopter des technologies de culture plus productrices qui sont nécessaires pour l'amélioration des conditions de pauvreté dans les zones rurales et aussi pour le renforcement de la sécurité alimentaire nationale.**

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Contents

Introduction

Sorghum [*Sorghum bicolor (L.)* Moench] and pearl millet *(Pennisetum glaucum)* are Mali's most important cereal crops in terms of both production, area sown as well as per capita consumption (IER 1993; FAO 1995). Indeed, in the period 1984-1994, these two cereals together accounted for well over 60% of the total cereals sown, produced, and consumed in the country (Table 1). If sorghum and pearl millet are predominant in Mali as in most Sahelian countries, it is because they are well-adapted to the Sahelian agroecologies which are characterized by low rainfall, high temperatures, and drought, and are generally unsuitable for the production of other grains unless irrigation is available (FAO and ICRISAT 1996). There is, however, a decreasing trend in the per capita consumption of sorghum and pearl millet, more as a result of the combined effect of increasing population and declining productivity than a shift in consumer preference away from these two cereals (FAO and ICRISAT 1996).

Conscious of the need to feed the rising population without relying too much on imports, the Malian government created the Institut d'Economie Rurale (IER) in 1960 to bring science to bear on agricultural policy and technology development. As part of this effort, two research stations were established: the Sotuba station with a mandate for sorghum research; and the Cinzana station with a mandate for pearl millet research. Since then, sorghum and pearl millet improvement research has evolved with important internal and external investments and in collaboration with various international agricultural research centers (e.g., IRAT, ICRISAT, and CIRAD). This collaborative sorghum and millet improvement research has mainly targeted the three most drought-prone areas (Segou, Mopti, and Koulikoro) of the five regions (Kayes, Koulikoro, Segou, Sikasso, and Mopti) which form the bread basket of Mali (Figure 1). Over the years, it has led to the development of a number of important seed-based technologies, some of which have been released and successfully adopted by farmers in these areas.

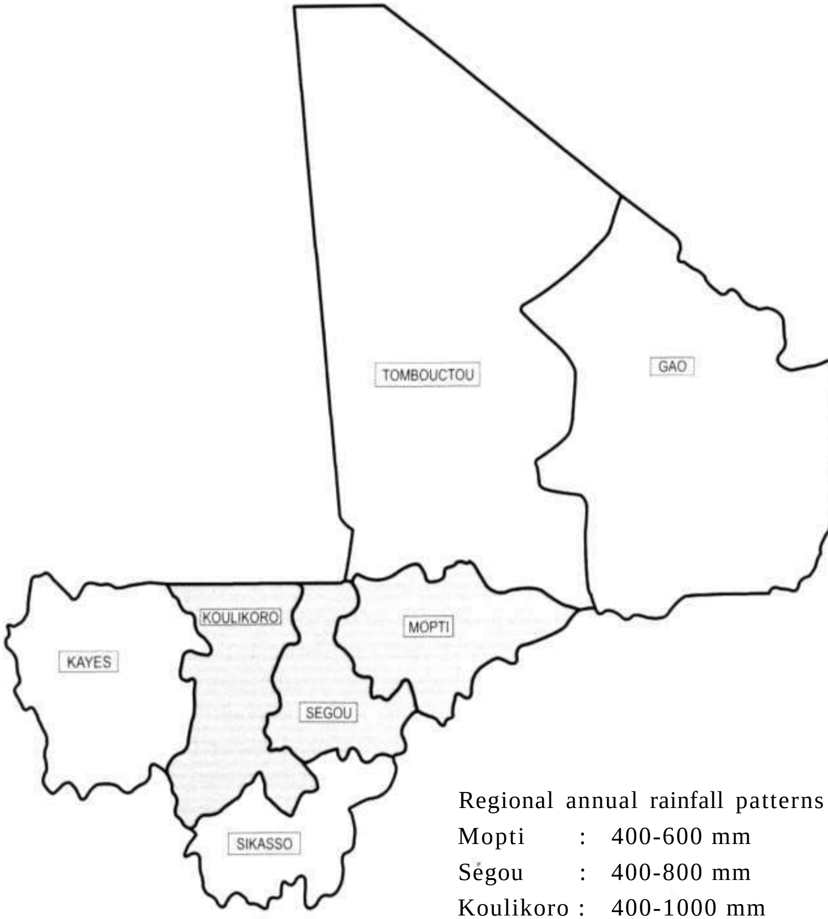

Figure 1. Map of Mali showing the study regions.

Table 1. Cereal area ('000 ha), production ('000 t), consumption (kg capita^{-1} year^{-1}), and imports ('000 t) in Mali.

Crop	1963-1973	1974-1984	1984-1994
All cereals			
. Area sown	1324	1507	2257
. Production	1007	1188	1963
. Consumption	172	163	190
. Imports	52	129	152
Sorghum + pearl millet			
. Area sown	1011 (76%[1])	1205 (80%)	1817 (80%)
. Production	742 (74%)	877 (74%)	1389 (71%)
. Consumption	126 (73%)	112 (69%)	128 (67%)
. Imports	-	-	-
Maize			
. Area sown	95 (7%)	74 (5%)	178 (8%)
. Production	81 (8%)	85 (7%)	221 (11%)
. Consumption	16 (9%)	15 (9%)	22 (12%)
. Imports	12 (23%)	29 (22%)	17 (11%)
Rice			
. Area sown	165 (12%)	174 (12%)	222 (10%)
. Production	151 (15%)	186 (16%)	327 (17%)
. Consumption	21 (12%)	25 (15%)	31 (16%)
. Imports	11 (21%)	41 (32%)	70 (46%)

1. Figures in parentheses are percentages of the total for all cereals. For example, the average area sown to sorghum and pearl millet together was 181 7000 ha (i.e., 80%) of the total cereals area (2 257 000 ha) in Mali during 1984-1994.

Source: FAO 1995.

The development of these technologies has followed two breeding approaches: (1) selection of the best materials from collections of local landraces; and (2) selection based on introduced materials and their crosses with landraces. The first breeding scheme of collecting, testing, and purifying local landraces has offered farmers seed-based technologies with modest yield gains but with the advantage of farmer familiarity with the materials. The second breeding approach, based on crosses with exotic germplasm and pedigree selection, has led to the development of high-yielding and early-maturing varieties which require significant improvement in the farmers' traditional cropping systems as well as the rural infrastructure (e.g. improved seeds availability, credit system) for their adoption. For these and other reasons, varieties developed through plant breeding have not been widely adopted. This merits a detailed study.

This study is a collaborative effort by ICRISAT, IER, and PNVA (Programme National de la Vulgarisation Agricole) to assess the economic impact of investments in pearl millet and sorghum improvement research in Mali. Its specific objectives are

- to determine the adoption rates of improved sorghum and millet varieties developed and released in Mali;
- to elicit information on farmers' perceptions of these varieties, and identify the constraints to the adoption of improved sorghum and pearl millet seed-based technologies; and
- to quantify the economic returns to investments in sorghum and millet improvement research and extension in Mali.

The conceptual framework used in this study considers the evaluation of research impact as a process starting with the identification of a set of research investments for a specific project designed to address a major agricultural problem. For this investment to produce impact, two conditions are required: First, the research project must be successful in producing the expected output or improved technology. This requirement is more of a necessary condition for ex-ante impact assessments than for ex-post cases, since the probability of success is known in the latter cases but must be estimated in the former. Second, the generated technology must be adopted to a significant extent by the end-users, farmers (Bantilan 1996a). The adoption of the improved technology then is expected to improve the productivity of inputs and change farm cost structure in a way that allows the supply of a greater output to markets at reduced prices. This process results in welfare gain to consumers, producers, and society as a whole.

Methodology

This section presents the survey and analytical methods used to collect the necessary primary data and guide the logic of the benefits-evaluation process.

Farm-level surveys

Farm-level surveys were conducted to determine the rates of adoption of sorghum and pearl millet varieties using structured survey questionnaires, which were structured into six modules covering the period between 1990 and 1995. Their basic contents are summarized in Table 2.

A multiple-stage sampling scheme was used to select the study sites and participant farmers for the on-farm surveys. The first stage consisted of reviewing national agricultural statistics and purposively selecting the three driest regions (Mopti, Segou, and Koulikoro) out of the five which form the bread basket of Mali. Koulikoro is generally the wetter of the three, with an average annual rainfall of 877 mm over the last 15 years. Its soils are mostly sandy and clayey with low pH. The major cereal crops grown in this region are sorghum, pearl millet, and maize. The Segou region has an average annual rainfall of about 700 mm, but it can reach as high as 950 mm in some years and fall as low as 450 in others. Its soils are generally sandy and most suitable for pearl millet farming. The other important cereal grains in the region are sorghum, maize, and rice. The Mopti region, with an average annual rainfall of 500 mm, is the driest of the three study regions. Its soils are sandy and poor, and are mostly suitable for pearl millet cultivation. Rice and sorghum are secondary cereals in Mopti. The purpose of the first stage of sampling was to obtain regions representative of the total research and extension target zone for sorghum and millet in Mali.

Table 2. Structure of the survey questionnaires used for the study of adoption of sorghum and pearl millet varieties in Mali.

Module	Basic contents/information sought
1	Socioeconomic characteristics of farmers, including household size, landholding and labor structure, education, farm equipment possession, and use of farmyard manure and commercial fertilizers.
2	Characteristics of improved varieties including year of adoption, year of abandonment, whether adopted additionally or in place of an existing cultivar, and reasons for abandonment.
3	Reasons for the adoption of new varieties (i.e., farmers' preferences of plant traits).
4	Constraints to adoption of improved technologies.
5	Information on production system and patterns of sorghum and pearl millet areas and production.
6	Information about farm cost structure (i.e., labor requirement for activities, seeds, organic and inorganic fertilizers, and farm equipment use).

The second stage consisted of a random selection of three sectors from each of the three regions. This led to the random selection of the Koulikoro, Banamba, and Ouelessebougou sectors from the Koulikoro region; Braoueli, Macina, and Segou from the Segou region; and Bankass, Djenne, and Koro from the Mopti region.

In the third stage, random samples of villages were selected from each sector. This led to the selection of a total[1] of 16 villages across the three sectors in the Mopti region, 19 villages from the Segou region, and 18 villages from the Koulikoro region. Having identified the villages, households were selected at random with the number of sample households being proportional to the size of the village. On-farm survey questionnaires were thus administered to a total of 530 farmers from a total of 53 villages distributed over the three study regions (Table 3).

Two difficulties were faced during the field work (questionnaire implementation). First, there were language barriers in Mopti, especially in the sectors of Koro and Bankass where Dogon is the principal language. On many occasions a third person was called upon to serve as interpreter between the Bambara enumerator and the Dogon farmer.

1. Initially, 20 villages were randomly selected in each region, but for some practical difficulties on the field, enumerators were actually able to visit and work only in 16 villages in Mopti, 18 in Koulikoro, and 19 in Segou.

Table 3. Sample size[1] of pearl millet and sorghum farmers in villages selected in each study region.

		Pearl millet farmers		Sorghum farmers	
Region	Village	Total sample	Adopters	Total sample	Adopters
Mopti	Dangatene	9	8	4	0
	Dimbal	8	1	0	0
	Dounde	7	2	0	0
	Gouifal	10	8	2	1
	Kamikoro	8	3	4	0
	Keniorodougou	9	8	4	0
	Kouyentobo	9	7	0	0
	Lere	10	8	3	0
	Logon	6	1	0	0
	Madiama	8	2	8	6
	N'biabougou	7	0	8	4
	N'goune	4	0	3	0
	Sirabougou	7	0	9	5
	Siratinti	4	8	8	2
	Tere	10	0	5	2
	Yentela	6	0	7	2
	Total (16 villages)	122	56	65	22
Segou	Fambougou	2	2	1	0
	Nabougou	7	3	3	2
	Sinebougou	7	3	0	0
	Kondogola	3	1	6	3
	N'gara	12	12	2	2
	Fakola	8	0	2	0
	Bambougou	7	4	0	0
	Bachembougou	9	0	5	0
	Yassalam	5	0	3	0
	Zanabougou	8	0	5	0
	Thiongoni	5	1	0	0
	Famoryla	6	2	5	2
	Kele	8	8	7	4
	Kakola	3	0	4	1
	Sebela	10	10	3	0
	Boundo-Bamanan	6	5	4	4
	Sekoro	6	2	0	0
	Douga	1	0	0	0
	Falema	10	9	0	0
	Total (19 villages)	123	62	50	18

Continued

Table 3. *Continued*

Region	Village	Pearl millet farmers		Sorghum farmers	
		Total sample	Adopters	Total sample	Adopters
Koulikoro	Beneco	6	0	10	0
	Tinkele	3	0	10	5
	Sirado	10	10	10	2
	Tioribougou	6	0	10	3
	Doumba	7	5	10	6
	Fanssebougou	9	8	9	7
	Samakele	7	1	10	5
	Tomba	1	0	10	8
	N'tentoukoro	0	0	10	1
	Sido-Djitomou	0	0	10	9
	Sougoula	0	0	10	10
	Kongola	0	0	10	8
	Kenioroba	0	0	10	1
	Kononi-Sirado	0	0	10	6
	Faladje	0	0	15	2
	Samako	0	0	11	10
	Nankilabougou	0	0	10	8
	Kolle	0	0	9	6
	Total (18 villages)	49	24	184	97

1. Ten farmers were randomly selected from each village for the survey, but the sum of sorghum and millet growers is not necessarily 10 because some farmers grow both cultures. For example, in the village of Dangatene in Mopti, sorghum and pearl millet growers add up to 13 (i.e., 9+4). This means that 3 farmers grow both crops.

Secondly there was difficulty in identifying whether the variety considered by farmers as improved was really one developed through the research process. Indeed, within a few years after being introduced in the rural areas, improved varieties of sorghum and pearl millet usually assume local names that have little or no resemblance to those originally given by scientists at the research station. They also degenerate and get mixed up with local varieties after years of cultivation under the informal seed production and distribution regime characterized by farmer-to-farmer operations. This second problem is mitigated by including in the research team extension agents and sorghum and pearl millet breeders at the national (IER) and international (ICRISAT, CIRAD-CA) levels. The varieties declared as 'improved' by farmers were subsequently verified by extension agents and breeders; and only those thus confirmed were considered in the computation of adoption rates and in the evaluation of returns to research.

Analytical method

The analytical approach used in this study to measure the size and distribution of welfare gains from the adoption of improved seed-based technologies is based on the principle of economic surplus. The essence of this approach is that adoption of a new technology is expected to bring improvements in the production and consumption environment. For example, application of improved sorghum varieties with accompanying crop management practices is expected to improve the farm cost structure and crop productivity, and make farmers more efficient in their input use. This ultimately translates into increased output at a lower unit cost of production, improving both the producer's and the consumer's welfare. Producers benefit from increased productivity and reduced unit costs of production. Consumers benefit from consuming larger quantities now available at lower market equilibrium prices. These welfare gains for producers and consumers are known as producer surplus and consumer surplus, respectively (Bantilan 1996b).

To visualize these welfare gains, it is useful to consider the supply and demand model as a representation of the production and consumption environment. Taking the supply curve as a reference, the producer surplus is measured by the area under the market equilibrium price and above the supply curve. As the supply curve shifts downward as a consequence of research-induced technological change, the producer surplus expands[2]. Similarly, taking the demand curve as a reference, the consumer surplus is measured by the area under the demand curve and above the market equilibrium price. Downward movement of the supply curve also increases the consumer surplus. The sum of the producer and consumer surpluses represents the economic surplus. Assuming linear demand and supply curves (for ease of computation but at some cost of accuracy) within a closed economy (where supply = production), the mathematical forms of producer surplus (PS), consumer surplus (CS), and economic surplus (ES) are as follows (Bantilan 1996a):

$$PS = K \times Q - \frac{(\beta \times K)}{(\beta + \alpha)} Q + \frac{1}{2} \beta \left[K - \frac{(\beta \times K)}{(\beta + \alpha)} \right]^2 \quad (1)$$

$$CS = \frac{(\beta \times K)}{(\beta + \alpha)} Q + \frac{1}{2} \alpha \left(\frac{\beta \times K}{\beta + \alpha} \right)^2 \quad (2)$$

2. This is a consequence of the linear demand curve assumed, for non-linear demand curve with constant price elasticity. This may not hold if the price elasticity of demand is less than unity in absolute value.

$$ES = PS + CS \quad (3)$$

$$= K \times Q + \frac{1}{2}\alpha\left(\frac{\beta \times K}{\beta + \alpha}\right)^2 + \frac{1}{2}\beta\left[K - \frac{(\beta \times K)}{(\beta + \alpha)}\right]^2$$

Where,

β = Slope of supply curve;

α = Slope of demand curve;

Q = Output; and

K = Parallel cost-reducing effect of research.

Equation (3) represents the total annual benefit accruing to consumers and producers. This single-period static model is the simplest version of the economic surplus approach applied in measuring research benefits (Bantilan 1996b). It assumes a parallel shift in the supply function in a nontraded goods economy where economic surpluses with and without research are compared. The assumption of a closed economy is relevant in the case of Mali where international trade in sorghum and pearl millet is limited.

There are also important costs associated with improved technologies. To correctly estimate the extent of the impact of research, the string of benefits accruing to society over the lifetime of the technologies must be compared with the total research and diffusion investments. The estimation of these costs demands an understanding of the research process that generated the technologies. This is undertaken in the next section.

Overview of sorghum and pearl millet research

Sorghum and pearl millet improvement research in Mali began in 1962 with the creation of IER. But until the Division de la Recherche Agronomique (DRA) was established in 1970, the research was conducted on a contractual basis exclusively with a number of French research institutes, notably the Institut de Recherche Agronomique Tropicale (IRAT). The IRAT collaborative program was phased out in 1975, and the ICRISAT/UNDP partnership program in Burkina Faso took over from 1975 to 1987. Simultaneously, the USAID/ICRISAT/IER bilateral program was conducted from 1978 to 1991. The ICRISAT West Africa Sorghum Improvement Program (WASIP) was formally launched on a regional basis in 1988. Until then, the Burkina Faso and Mali programs were independent country programs. In 1989, CIRAD-CA (Centre de cooperation internationale en recherche agronomique pour le developpement culture annuelle) (formerly IRAT) entered into partnership with ICRISAT-WASIP at the Samanko (Mali) research station, thereby reinforcing the sorghum improvement research effort in Mali.

Two strategically important research stations were established at Sotuba and Cinzana according to the regional importance of sorghum and millet in the production systems. The Sotuba research station, located near Bamako in Koulikoro region, was established for sorghum (and maize) improvement research for Koulikoro and the wetter southernmost regions where sorghum follows rice and maize as the most important cereals.

The Cinzana research station, located in Segou region, was established for pearl millet research targeting the two central regions (Mopti and Segou) where pearl millet remains by far the most important cereal crop, and where food security is most threatened because of erratic rainfall.

Objectives, methods, and achievements

The principal objective of sorghum research in Mali has been grain yield improvement in order to address the problem of low productivity and food insecurity (Luce 1995). This overall objective was pursued essentially through two approaches. First, breeding efforts sought to improve on the existing landraces characterized by limited grain productivity but with great adaptability to local agroecological conditions. This involved collecting, testing, purifying, and offering to farmers the best of the local varieties with which they are familiar (Shetty et al. 1991; Luce 1995). This resulted in the selection of several improved local landrace varieties of which M_2D_2, NKK, NBB, M_9D_3 and HKP (for pearl millet) and Tiemarifing, Seguetana, and the CSM series (for sorghum) are the most important. In the second approach, breeding efforts were oriented toward introductions and selections using exotic germplasm with characteristics believed to be important for sorghum and pearl millet improvement and intensification in rainfall-deficient areas: short duration (<65 days to flowering), drought tolerance, emergence in high soil temperature, high yield, and short plant height[3].

Achievements through this second approach include the development and release of varieties such as IBMV 8001, SOSAT-C88, Toroniou, Benkadiniou, Mangakolo and Guefoue (for pearl millet); and CE 151, ICSV 1063 BF, ICSV 1079 BF, CIRAD 406 (ICSU 2001), CGM 19/9-1-1, ICSU 901, and the Malisor series (for sorghum). These varieties have been tested and released for diffusion in different recommendation domains in Mali. Tables 4 and 5 list and characterize some of the varieties currently under cultivation in farmers' fields. As can be

3. Despite their great adaptability and grain quality, landrace varieties have a lower yield potential and are too tall to respond to intensive agronomic techniques and efficiently use soil nutrients and fertilizers (Chantereau 1990).

Table 4. Characteristics of improved sorghum varieties in use in Mali, 1990-95.

Sorghum variety	Origin	Year of release	Cycle (sowing to maturity)	Plant height (cm)	Recommended domain (mm)	Grain yield (t ha^{-1})	Essential characteristics
Tiémarifing (Guinea type)	Mali	1973	120-150 days	350-450	800-1000	2.5-3 (on station) 1.5-2 (on farm)	Photosensitive; resistant to grain mold and long smut, good tô[1] quality
Sèguètana (Guinea type)	Mali	1973	120-125 days	350-450	600-800	1.5 - 2.0 (on farm)	Photosensitive; very good resistance to *Striga*
CSM 63-E (Guinea type)	Mali	1986	100-105 days	211	300-800	2-2.5 (on station) 1.5-2 (on farm)	Photosensitive; resistant to leaf diseases and long smut; very good tô
CSM 219 (Guinea type)	Mali	1986	100-106 days	214	400-800	2-2.5 (on station) 1.5-2 (on farm)	Photosensitive; resistant to leaf diseases and long smut; very good tô
CSM 388 (Guinea type)	Mali	1985	120-130 days	350-370	700-1100	1.5 - 2.5 (on station)	Photosensitive; resistant to leaf diseases and long smut; very good tô

Continued...

Table 4 *Continued*

Sorghum variety	Origin	Year of release	Cycle (sowing to maturity)	Plant height (cm)	Recommended domain (mm)	Grain yield (t ha^{-1})	Essential characteristics
CE 151 (Caudatum type)	Senegal	1985	90-95 days	110	300-700	2-2.5 (on station) 1.5-2 (on farm)	Photoinsensitive; good resistance to long smut; bad tô quality
ICSV 1063 BF (Caudatum type)	ICRISAT/ Burkina Faso	1989	105-110 days	180-200	600-800	3-3.5 (on station) 1.5-2 (on farm)	Photoinsensitive; high-yielding; tolerant to insect pests and diseases
ICSV 1079 BF (Caudatum type)	ICRISAT/ Burkina Faso	1989	100-105 days	180-200	600-800	3-3.5 (on station) 1.5-2 (on farm)	Photosensitive; high-yielding; tolerant to drought, insect pests and diseases

1. Tô is a millet, sorghum or maize-based dish traditionally consumed in Mali.

Sources: On-farm survey conducted by the authors in 1995; Dembélé and Sidibé 1988; and personal communications from Dr. J. Chantereau (CIRAD-CA) and Dr. D.S. Murty (ICRISAT-Mali), 1996.

Table 5. Characteristics of improved pearl millet varieties in use in Mali, 1990-1995.

Pearl millet variety	Origin	Year of release	Cycle (sowing to maturity)	Plant height (cm)	Recommended domain (mm)	Grain yield (t ha^{-1})	Essential characteristics
NKK	Mali	1973	100-110 days	250-300	450-600	2-2.5 (on station)	Photosensitive good resistance to drought, long smut, and mildew
HKP	Niger	1985	80-90 days (50% flowering)	190-200	300-800	1.5-2.5 (on station)	Tolerant to mildew and long smut; but sensitive to millet head miners; good tô quality
IBMV 8001	ICRISAT/ Bambey/ Senegal	1985	75-85 days (50% flowering)	225-300	300-800	1.5-2.5 (on station)	Tolerant to mildew and long smut; very good tô quality
SOSAT-C88	Mali	1989	80-85 days (50% flowering)	179-250	300-600	1.5-2.5 (on station)	Resistant to mildew; high and stable yield
Toroniou	Mali	1986	105-110 days	250-300	400-800	1.5-2 (on station)	Very good resistance to stem borers
Benkadiniou	Mali	1989	80 days (50% flowering)	250-300	700-900	1.8-2.5 (on station)	Tolerant to mildew, long smut and millet head miners; good tô quality
Mangakolo	Mali	1990	70-75 days (50% flowering)	250-300	400-800	1.5-2 (on station)	Tolerant to mildew, long smut, and millet head miners; good tô quality
Guéfoué	Mali	1992	70-75 days (50% flowering)	250-300	400-800	1.5-2 (on station)	Photosensitive; tolerant to mildew, long smut, and millet head miners

Sources: On-farm survey conducted by the authors in 1995; Dembélé and Sidibé 1988; and personal communication from Dr. O. Niangado (IER), 1996.

seen from these tables, different improved varieties were released simultaneously or about a year apart. This does not represent a duplication of effort but rather a response to farmers' tendency to adopt more than one variety as a strategy against crop failure and production risks. For example, Tiemarifing and Seguetana were released in the same year (1973) but adopted by farmers for different reasons: the first variety for its resistance to grain mold and long smut; and the second variety for its resistance to *Striga*[4].

An overview of sorghum and pearl millet extension services

Until recently, development organizations and national extension services were only indirectly interested in sorghum and pearl millet, through the development of "cash crops" such as cotton and groundnut. For example, the Compagnie Malienne pour le Developpement du Textile (CMDT) has shown interest in sorghum and millet production only in the context of crop rotation for a more sustainable cotton production. As for groundnut, its production for export has been so intensely promoted by Operation Arachidiere (OA), a government agency, that a cereal deficit was created in the groundnut production zones of Kayes, Bamako, and Koulikoro in the 1970s (Goita 1996). A number of government agencies have been established to organize and promote the transfer of agricultural technologies; but these have not been able to function properly for lack of logistics and adequate funding. After a review of the research-output delivery process, the PNVA was created in 1988. One of its fundamental objectives is to integrate its activities with those of other programs such as the National Seed Service (SSN), IER and collaborating institutions (e.g., ICRISAT, CIRAD-CA), and NGOs in the development and diffusion of agricultural technologies in the country.

The SSN is charged with the multiplication and distribution of improved seeds in Mali. Its activities include (1) preproduction demand analysis; and (2) training and information dissemination. Preproduction activities relate to the initial assessment of farmer requirements for improved seeds and the planning of production to meet their demands. The training and information dissemination unit ensures training for farmers, extension agents, and contract seed-growers who produce certified seed. Breeder's seed (prebase) is obtained from the research stations and multiplied into foundation seed from which certified seed is produced. Multiplication of foundation

4. Seguetana means *Striga* resistant in Bambara.

seed is done at nine SSN seed production farms ("antennes") located in different agroecological zones. Certified seed is produced by contract farmers in about 20 villages under special UNDP/FAO financing, and diffused to farmers by PNVA.

Between 1989 and 1992, a total of 568 t of improved sorghum and 295 t of improved pearl millet varieties were multiplied and distributed to farmers through the formal seed sector[5] (Table 6). The dominant sorghum varieties multiplied and extended to farmers were CSM 388 (42% of total), CSM 63-E (32%), and Tiemarifing (20%). Improved sorghum seed multiplication and distribution rose from 75 t in 1989 to 135 t in 1990, reaching its peak of 284 t in 1991. For pearl millet, the dominant improved varieties multiplied and distributed through the formal seed sector were IBMV 8001 (28% of total), NKK (25%), HKP (25%), and Toroniou (21%). As with sorghum, production and distribution of improved millet seeds rose gradually from 9 t in 1989 to 37 t in 1990, to reach a peak of 155 t in 1991 (Table 6). Since 1992, both sorghum and millet seed production by contract farmers fell drastically as subsidies and guaranteed prices were removed following the phasing out of the special UNDP/FAO project.

There are important informal channels for improved seed diffusion in Mali. Farmer-to-farmer transfer is probably the most important diffusion mechanism. However, the volume of seeds passing through this channel has not been documented. It is common for farmers to pick up seeds of improved sorghum and millet varieties from demonstration plots during open-house visits to research stations or farmers' fields. Nongovernmental organizations also constitute an important element in the informal transfer of improved seeds. The best-known NGOs active in seed multiplication and distribution to farmers in Mali include World Vision, Voisins Mondiaux, PFDVS/Segou, and the Catholic church missions in drought-prone areas. The successful introduction of ICRISAT's sorghum varieties ICSV 1063 BF and ICSV 1079 BF in the Kolokani area in Koulikoro region is an outstanding example of the Catholic church's active involvement in agricultural technology transfer in Mali.

5. The records examined were incomplete as some of the seed production farms had not reported their activities. The total improved seed production reported here should be viewed as a minimum.

Table 6. Trends in the production (for sale) of seeds (R_2) of improved sorghum and millet varieties in the formal seed sector in Mali, 1989-1992.

	1989		1990		1991		1992			
Variety	Output (t)	Yield (t ha^{-1})	Output (t)	Yield (t ha^{-1})	Output (t)	Yield (t ha^{-1})	Output (t)	Yield (t ha^{-1})	Total output (t)	Average yield (t ha^{-1})
Sorghum										
CSM 388	46.35	1.36	61.13	1.40	109.9	1.20	21.22	1.22	238.60	1.30
CSM 63-E	5.00	0.60	49.05	0.93	103.3	1.16	26.26	0.93	183.60	0.90
CSM 151	7.64	0.50	0.81	0.35	4.08	0.70	1.20	1.00	13.73	0.64
CSM 219	15.86	1.20	–	–	–	–	–	–	15.86	1.20
Tiémarifing	–	–	23.59	1.10	66.4	1.60	25.70	1.40	115.69	1.36
Total	74.85	0.915	134.58	0.94	283.6	1.165	74.38	1.138	567.31	1.08
Millet										
M 903	3.98	0.90	0.90	0.70	7.16	1.00	–	–	12.04	0.866
NKK	0.95	0.50	22.35	0.80	34.00	1.00	15.60	0.93	72.90	0.807
HKP	4.23	0.30	11.62	0.40	33.75	0.80	15.87	0.60	65.47	0.525
IBMV 8001	–	–	–	–	52.96	1.02	30.79	1.30	83.75	1.020
Toroniou	–	–	1.96	0.70	62.96	0.93	32.27	1.30	97.19	0.970
Total	9.16	0.566	36.73	0.65	154.83	0.95	94.53	1.03	295.25	0.799

Source: SSN database.

Estimation of research and extension service costs

For the purpose of this study, IER and ICRISAT are considered the main sorghum and pearl millet research collaborators, and PNVA the agency that has diffused the technologies under study. The contribution of any other collaborating institution is accounted for under IER, ICRISAT, or PNVA. As mentioned earlier, NGOs have contributed in the distribution of improved seed in the drought-prone areas of Mali. But for the purpose of this study, the costs incurred by NGOs are treated as "sunk costs", i.e., expenditures whose primary purpose is other than sorghum and pearl millet improvement R&D.

Research costs incurred by IER

Data on the annual costs of research on sorghum and pearl millet incurred by IER for the period 1994-1995 were obtained from IER. This information together with further discussions with senior scientists and administrators of IER led to the research cost estimates presented in Table 7e.

Research costs incurred by ICRISAT

The involvement of ICRISAT in sorghum and pearl millet improvement research in Mali started in 1977 as a bilateral program, and later as a joint program with CIRAD-CA. Using program budget information available from alternative sources (Shetty et al. 1991; ICRISAT Annual Reports 1987, 1988, and 1989; and personal communications with Dr. D.S. Murty, 1996), costs incurred on ICRISAT research activities were estimated at US$ 105 500 in 1979 when the first breeder joined the ICRISAT bilateral program, and US$ 380 250 in 1991, when the bilateral program was phased out, replaced by the ICRISAT West Africa Sorghum Improvement Program in which CIRAD-CA has been collaborating actively since 1989. These include the expenditures of the bilateral program (1979-1991), the joint ICRISAT/CIRAD Sorghum Improvement Program (1989-1995) as well as the expenditures on the development of the ICSV series which started in 1977 from ICRISAT-Burkina Faso. The bases for these cost estimates are detailed in Tables 7a, 7b, and 7c.

Table 7a. Cost estimates of the ICRISAT bilateral program in Mali.

First year of funding	Total funds (US$)	Source of funding	Purpose of funding
1976	Not available	Ford Foundation	Creation of the ICRISAT-bilateral program.
1979	500 000	USAID	Research funding for 3 years: 1979, 1980, and 1981.
1981	3 750 000	USAID	Research funding for 5 years: 1982, 1983, 1984, 1985, and 1986.
1983	4 000 000	USAID	Research funding for 5 more years: 1987, 1988,1989, 1990, and 1991.

Source: Authors' computations are based on funding information available from Shetty et al. 1991.

Table 7b. Estimation of sorghum and pearl millet research costs (US$) for the ICRISAT program[1] in Mali.

Years	Total program budget[2]	Budget for				
		Training activities[3]	All other activities[4]	Sorghum/ millet research[5]	Sorghum research[6]	Millet research[7]
1979	166 667	20 000	16 667	130 000	65 000	65 000
1980	166 667	16 000	16 667	134 000	67 000	67 000
1981	166 667	21 000	16 667	129 000	64 500	64 500
1982	750 000	6 000	75 000	669 000	334 500	334 500
1983	750 000	60 000	75 000	615 000	307 500	307 500
1984	750 000	61 000	75 000	614 000	307 000	307 000
1985	750 000	60 000	75 000	615 000	307 500	307 500
1986	750 000	60 000	75 000	615 000	307 500	307 500
1987	800 000	47 000	80 000	673 000	336 500	336 500
1988	800 000	34 000	80 000	686 000	343 000	343 000
1989	800 000	19 000	80 000	701 000	350 500	350 500
1990	800 000	4 000	80 000	716 000	358 000	358 000
1991	800 000	0	80 000	720 000	360 000	360 000

1. ICRISAT program here includes CIRAD and the West and Central Africa Sorghum Research *Network (WCASRN).*
2. The annual budget was calculated by dividing total period funds (see table 7a) by the number of *years for* which the funds were provided.
3. The training budget was estimated using the information on the number of M.S. and Ph.D. students trained and the training periods provided in Shetty et al. 1991, pp. 19, 20, 75-76.
4. The program aimed to improve (1) sorghum and millet, (2) forage production, (3) animal traction, (4) pigeonpea production, and (5) training of national scientists. About 10% of the total annual budget was spent on objectives (2), (3), and (4).
5. The sorghum and millet research budget is the total program budget, net of the training and other program budgets.
6. The sorghum research budget is half of the total budget for sorghum and millet research.
7. The millet research budget is half of the total budget for sorghum and millet research.

Source: Authors' computations are based on information available from Shetty et al. 1991, p. viii.

Table 7c . Basis for estimating ICRISAT/WASIP research costs.

Crop improvement research team	Total research cost ($)	Proportion of time in project (%)[3]	Budget allocation ($)
1977-1988[1]			
2 Principal scientists (breeders)	140 000	20	28 000
2 Research assistants	11 500	20	2 300
2 Field technicians	6 500	20	1300
2 Drivers	3 000	20	600
4 Regular work force	4 000	20	800
Operating expenses	75 000	10	7 500
Total annual expenses	240 000		40 500
1989-1995[2]			
2 Principal scientists (breeders)	230 000	5	11 500
2 Research assistants	12 000	10	1200
2 Field technicians	7 500	10	750
2 Drivers	3 500	10	350
4 Regular work force	4 500	10	450
Operating expenses	60 000	10	6 000
Total annual expenses	317 500		20 250

1. The research expenses incurred during the first two years of the period 1977-88 concern the initial research activities for ICSV 1063 BF and ICSV 1079 BF by K V Ramaiah in Burkina Faso, as well as pearl millet research activities by S N Lohani. The research for the two sorghum varieties as well as for some pearl millet technologies (e.g., Benkadinio) were completed at Samanko, when ICRISAT moved from Burkina Faso to Mali.

2. By 1989, most of the technologies under assessment in this study were more or less developed, so that research on them was reduced mostly to adaptation, and diseases and pest resistance trials for further improvement. Research costs for the period 1989 -1995 (for the varieties considered in this study) were estimated at $20 250 annually.

3. This is based on discussions with senior scientists who have knowledge about the ICRISAT/WASIP research program and its activities.

Source: Authors' computations were based on the annual budget reconstructed with guidance from senior ICRISAT scientists who have knowledge about the ICRISAT/WASIP research program and its activities.

Costs of extension services incurred by PNVA

The principal Malian government agency responsible for agricultural technology diffusion, PNVA came to existence only in 1988. In this study, as mentioned earlier, all agricultural extension systems before and after 1990 have been assimilated in PNVA. Thus, the intervention of PNVA covered three periods: 1973-1975, 1976-1982, and 1983-1995. Extension activities and associated expenses over these periods were estimated with the guidance of senior extension officers who have knowledge about the technologies under study. The results are presented in Table 7d.

Table 7d. Annual costs incurred on extension services by the PNVA.

Period	Extension activities over the periods	Expenditure (US$)
1973-1975	On-farm demonstrations	5 500
	Seed multiplication and distribution	9 500
	Operating expenses	12 000
	Average annual expenditure	27 000
1976-1982	On-farm demonstrations	11 500
	Seed multiplication and distribution	19 500
	Operating expenses	15 000
	Average annual expenditure	45 500
1983-1995	On-farm demonstrations	20 000
	Seed multiplication and distribution	19 500
	Operating expenses	25 000
	Average annual expenditure	64 500

Note: Staff salaries and benefits are treated as "sunk costs", that is costs which would occur even if these extension activities were not carried out. Therefore, they were omitted in the calculations.

Table 7e summarizes the estimated research and extension service costs incurred on the improvement and diffusion of sorghum and pearl millet varieties since 1969. In the earlier years (1969-1975), all the research costs were incurred by IER and the extension costs by PNVA. Between 1976 and 1982, IER contributed 17% of the total research and extension costs, compared with 59% for ICRISAT and 24% for PNVA. Between 1983 and 1995, ICRISAT's contribution reached 68% and those of IER and PNVA fell slightly to 15% and 17%, respectively.

Table 7e. Breakdown of the research and extension costs (in US$) for sorghum and millet improvement in Mali.

Year	IER	ICRISAT[1]	PNVA	Total costs
1969	17 500	0	0	17 500
1970	17 500	0	0	17 500
1971	17 500	0	0	17 500
1972	17 500	0	0	17 500
1973	17 500	0	27 000	44 500
1974	17 500	0	27 000	44 500
1975	17 500	0	27 000	44 500
1976	32 331	0	45 500	77 831
1977	32 331	40 500	45 500	118331
1978	32 331	40 500	45 500	118331
1979	32 331	105 500	45 500	183 331
1980	32 331	107 500	45 500	185 331
1981	32 331	104 500	45 500	182 331
1982	32 331	374 500	45 500	452 331
1983	57 731	347 500	64 500	469 731
1984	57 731	347 500	64 500	469 731
1985	57 731	347 500	64 500	469 731
1986	57 731	347 500	64 500	469 731
1987	57 731	377 000	64 500	499 231
1988	57 731	383 500	64 500	505 731
1989	57 731	370 750	64 500	492 981
1990	57 731	378 250	64 500	500 481
1991	57 731	380 250	64 500	502 481
1992	57 731	20 250	64 500	142 481
1993	57 731	20 250	64 500	142 481
1994	57 731	20 250	64 500	142 481
1995	57 731	20 250	64 500	142 481

1. ICRISAT here includes CIRAD-CA, its collaborating institution.

Source: Authors' estimates.

Results and discussion

This study produced two types of results: the adoption survey results and the impact assessment results.

Adoption survey results

The adoption study was designed to track, for the period 1990-1995, the spread of improved sorghum and pearl millet technologies released in Mali. In the process, important information was collected on the farmers' socioeconomic characteristics that are likely to influence adoption behavior.

Socioeconomic characteristics of farmers

The farmers' socioeconomic characteristics about which information was collected included: education level[6]; size of household and family labor; experience; membership in village-level association; access to land, agricultural equipment, and extension services; commercial and organic fertilizer use; and sources of first seeds of improved varieties.

The survey results indicate that most farmers in the study regions did not have formal education, as nearly 70% of the sampled farmers were unable to comprehend extension messages communicated orally in French or written in French or in the local language. Only 7% of the farmers in the sample were able to read, write, and speak French and the local language. The average household size was about 22 people, of whom 9 were active family members. Households in the Koulikoro region, however, tended to have fewer active members (about 6) than farm households in Mopti (about 11) and Segou (about 9) regions. They also tended to have less access to land (about 13 ha) than households in Mopti (about 19 ha) and Segou (about 17 ha). The per capita household landholding is thus less than 1 ha everywhere. The Koulikoro farmers, however, were more experienced in sorghum/millet farming (21 years) than their counterparts in Mopti (17 years) and Segou (18 years). In all the three regions, farmers tended to participate in village-level associations, had access to extension services, and utilized more farmyard manure than commercial fertilizers in sorghum/millet production. Table 8 summarizes these results.

6. The education most relevant at the farm level concerns the farmer's ability to comprehend technological messages communicated in French or written in the local language.

Table 8. Summary of the socioeconomic characteristics of farmers in Mali.

Farmer characteristic	Mopti	Segou	Koulikoro
Household size	23	22	22
Total household landholding	19 ha	17 ha	13 ha
Household landholding per capita	0.83 ha	0.77 ha	0.59 ha
Years of experience of head of household	17 years	18 years	21 years
Proportion of farmers with no education	74%	67%	55%
Village-level association membership	80%	72%	100%
Proportion of farmers with access to extension services	99%	92%	82%
Basic farm equipment utilization	95%	99%	100%
Commercial fertilizer utilization	1%	1%	0.5%
Farmyard manure utilization	98%	99%	100%

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

The farmer-to-farmer channel remains the primary source of information and first seeds of improved varieties (Table 9), although the farmers insisted that they have a good relationship with the extension services. However, this informal channel of information and seeds diffusion was less important in Segou. This is perhaps best explained by the presence of the SSN in the region.

Table 9. Importance of various sources of information about varieties and first seeds of new varieties in three regions of Mali.

	Mopti region		Segou region		Koulikoro region		All three regions	
Sources	Information on varieties	First seeds	Information on varieties	First seeds	Information on varieties	First seeds	Information on varieties	First seeds
Other farmers	86%	95%	6%	11%	66%	62%	61%	61%
Extension agents	9%	5%	50%	44%	8%	9%	14%	13%
Other villages	0%	0%	0%	6%	4%	7%	1%	0.73%
Seed service	5%	0%	33%	39%	1%	0%	7%	10%
NGOs	0%	0%	11%	0%	21%	21%	16%	15%
Local markets	0%	0%	0%	0%	0%	1%	0%	0.73%

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

Adoption rates of improved sorghum and pearl millet varieties

Ultimately, the real impact of an applied plant breeding/improvement program remains the proportion of the total targeted area sown to the improved varieties that have come out of the program. To put the IER/ICRISAT/CIRAD breeding program to this test, on-farm surveys were conducted and adoption rates computed on the basis of the survey data. The rates were not cumulative but estimated for each of the survey years (1990-1995) as the proportion of the area sown to improved varieties to the total rainfed area under the culture. These rates were then projected forward to the year 2018 and backward to 1973 for the years outside the survey period (see Adoption rate projection on page 34 for more details). This was necessary for the evaluation of the streams of benefits flowing from the adoption of improved varieties. The computed adoption rates are presented in Tables 10 and 11 for sorghum and pearl millet, according to the two breeding strategies described previously. For the purpose of analysis, the varieties developed through the first breeding strategy are referred to as "generation 1" varieties[7]; while those which came out of the second strategy are referred to as "generation 2" varieties. The adoption rates presented in Tables 10 and 11 show the substantial spread of improved varieties of sorghum and pearl millet in the drought-prone regions of the Malian bread basket (Mopti, Segou, and Koulikoro) targeted by sorghum and millet improvement research. These rates clearly represent a significant improvement over the rates (5%) reported in mid 1980 (Matlon 1990). But Matlon's report focused more on introduced varieties or those bred using exotic material than on improved landraces. In grouping the data according to the two breeding approaches indicated earlier, it was clear that most of the improved sorghum and pearl millet varieties adopted in Mali were based on local material. Five of the eight new varieties in use in farmers' fields were of the Guinea type, native to the West African ecosystem; the other three were of the Caudatum type from crosses using introduced germplasm (Table 4). Likewise, most of the pearl millet varieties in farmers' fields in Mali were developed out of Malian landraces (Table 5).

The observed preference of farmers for late-maturing varieties based on local material is due to the good adaptability of these varieties to the local environment and the traditional farming system, especially in years of normal or good rainfall. It is also due to the well-known food quality of their grains. In spite of their lower productivity, these improved local varieties are favored because they are familiar to

7. Because generation 1 varieties (or "farmer ready" varieties) have limited yield potential, they were not suitable for crop intensification. The development of generation 2 varieties was in response to the need for an intensification of sorghum and pearl millet production.

fanners who have mastered their cultivation over the years. These local varieties are also favored for their plant height (usually over 4 m) which makes their stalks useful as building materials. Nevertheless, there is an increasing trend toward adoption of introduced varieties, especially of sorghum over the period 1990-1995.

The adoption rates of improved varieties of sorghum are higher in Koulikoro than in the other two regions. This is explained by the importance of sorghum in the food system and the more favorable agroclimatic conditions in the region. The rates obtained in Mopti and Segou are relatively important given the secondary place this crop occupies in the food system of the two regions. As for pearl millet, the estimated adoption rates are higher in Segou than in the other regions. This is explained by the presence in the region of both the SSN and the Cinzana research station (the country's principal pearl millet research center). The lower rates observed in Mopti are mostly explained by the low density of technical extension services in the region. In Koulikoro too the low interest in pearl millet cultivation, demonstrated by the Operation Haute Vallee du Niger (OHVN), the region's principal development service, explains in large part the low adoption rates.

Adoption rates of improved varieties derived from exotic germplasm are observed to be generally higher for pearl millet than for sorghum. This is because pearl millet is more hardy than sorghum, and grows on poor sandy soil better than sorghum. Moreover, for pure-line varieties and composites of pearl millet, seed need not be bought on a regular basis but only to periodically replace stock.

Finally, it must be highlighted that although the estimated adoption rates of improved varieties are substantial, age-old landraces of sorghum and pearl millet still remain dominant in farmers' fields. This leads us to underline the fundamental fact, evident in Mali as elsewhere in Sahelian Africa, that the adoption of improved agricultural technologies is positively related to improvement in the farming environment as a whole. Local technologies will be preferred to new ones as long as the farming environment remains unchanged (Fig. 2). At present, point A seems to describe best the Mali situation.

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

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

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

Table 11. Adoption rates (as a percentage of the total rainfed millet area) of improved pearl millet varieties in Mali, 1990-1995.

	Mopti region		Ségou region		Koulikoro region		All three regions	
Year	Generation 1	Generation 2	Generation 1	Generation 2	Generation 1	Generation 2	Generation 1	Generation 2
1990	4	6	4	9	13	4	10	7
1991	6	6	4	10	15	4	11	8
1992	7	6	3	12	15	9	11	10
1993	8	7	3	16	16	12	12	13
1994	8	7	5	19	18	12	13	15
1995	9	8	5	24	20	17	15	19
Varieties	HKP NKK	SOSAT-C88 Toroniou Benkadiniou IBMV 8001	NKK	SOSAT-C88 Toroniou Benkadiniou	NKK	Mangakolo Guéfoué	NKK HKP	SOSAT-C88 Toroniou Benkadiniou IBMV 8001 Mangakolo Guéfoué

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

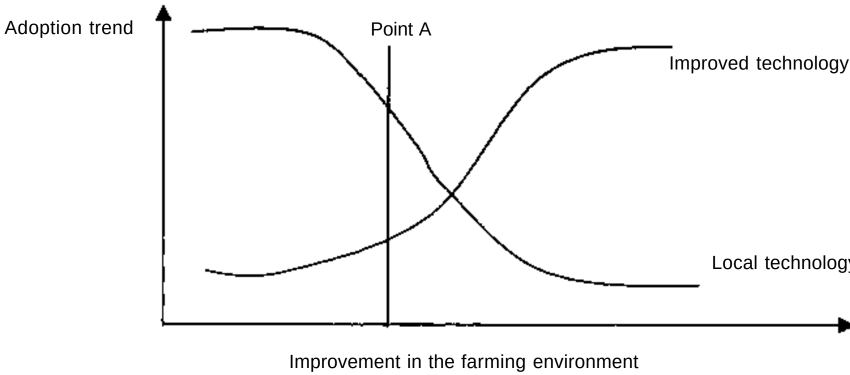

Figure 2. Relationship between the farming environment and adoption trends of local and improved technologies.

Source : Based on comments and suggestions from Alfa Maiga, DG of IER.

Reasons for adoption

Farmers cited several reasons for their adoption of improved sorghum and pearl millet varieties. The most important of them were short duration, high yield, and good food quality (Tables 12 and 13). For sorghum as well as for pearl millet, the early-maturity trait was ranked first in all the study regions, followed by high yield, food quality and *Striga* resistance, in that order. The high ranking of the short-duration trait is confirmation that drought is indeed the most important factor limiting coarse grain production in Mali as in most Sahelian countries. The frequency with which this trait was cited was higher in Mopti and Segou (the drier regions with average annual rainfall below 700 mm) than in Koulikoro (the wetter region of the three, with rainfall averaging 800 mm). Other supporting factors for the preference for short - maturing varieties include: risk hedging, and early end of hunger period (Ahmed et al. 2000). High yield, on the other hand, was most important in Koulikoro where sorghum and millet have to compete with other high-yielding crops such as maize and rice.

Table 12. Farmers' reasons for adoption of improved sorghum varieties in Mali.

Reasons for adoption	Mopti region	Segou region	Koulikoro region	Across the 3 regions
Sample size	22	18	97	137
Short duration	95%[1]	89%	76%	81%
High yield	50%	67%	78%	72%
Good food quality	32%	39%	27%	29%
Striga resistance	0%	6%	18%	13%

1. Percentages indicate the frequency with which a reason for adoption was cited.
Source: Results of on-farm survey, 1996.

Table 13. Reasons for adoption of improved pearl millet varieties in Mali.

Reasons for adoption	Mopti region	Segou region	Koulikoro region	Across the 3 regions
Sample size	56	62	24	142
Short duration	96%[1]	87%	92%	92%
High yield	57%	87%	75%	73%
Good food quality	36%	35%	38%	36%
Striga resistance	0%	2%	21%	8%

1. Percentages indicate the frequency with which a reason for adoption was cited.
Source: Results of on-farm survey, 1996.

By citing good food quality as a reason (albeit ranked third) for adopting improved sorghum and pearl millet varieties, farmers provided an important indication that breeding efforts have been successful in improving the grain quality of these new technologies. Farmers also acknowledged that some of the improved varieties have good resistance to *Striga,* the witchweed endemic to West and Central Africa, which severely reduces productivity on farms unable to afford existing *Striga* control methods.

Constraints to adoption

The large number of nonadopters shows that the majority of farmers in all three regions are still using traditional varieties of sorghum and pearl millet. To assess the importance of the limiting factors, their frequency distributions were computed and are presented in Table 14 for sorghum and Table 15 for pearl millet.

Table 14. Major constraints to adoption of improved sorghum varieties cited by nonadopting farmers in Mali.

Reasons for nonadoption	Mopti region	Segou region	Koulikoro region	Across the 3 regions
Sample size	43	32	87	162
Lack of information	80%[1]	84%	52%	66%
Lack of improved seeds	67%	66%	39%	52%
Decreasing soil fertility	14%	84%	12%	13%
Preference for locals	7%	16%	17%	14%

1. Percentages indicate the frequency with which a reason for nonadoption was cited.
Source: Results of on-farm survey, 1996.

Table 15. Major constraints to "adoption of improved pearl millet varieties in Mali.

Reasons for nonadoption	Mopti region	Segou region	Koulikoro region	Across the 3 regions
Sample size	66	61	25	152
Lack of information	68%[1]	57%	28%	57%
Lack of improved seeds	15%	46%	20%	48%
Decreasing soil fertility	14%	12%	16%	20%
Preference for locals	21%	33%	16%	26%

1. Percentages indicate the frequency with which a reason for nonadoption was cited.
Source: Results of on-farm survey, 1996.

The major reasons for nonadoption as shown in Tables 14 and 15 are: (1) farmers are not well-informed about the existence of improved varieties of sorghum and pearl millet and the cultural requirements of these technologies; this is an important constraint as it was cited with insistence by an overwhelming number of farmers throughout the study regions; this constraint will remain as long as national extension services coverage continue to be limited, and farmer-to-farmer contact remains the main channel for improved technology information dissemination and distribution. (2) the improved seeds are not always available when needed and in the required quantity; (3) soil infertility is a limiting factor; some of the improved varieties, especially the introduced ones, require a moderate level of fertilization for their productivity. When farmers cannot meet this requirement, they shy away from taking up the technologies; and (4) small farmers with limited land tend to avoid taking risky decisions; they are very often reluctant to give up the familiar traditional varieties for something new which may or may not work. This preference for local varieties is sometimes reinforced by past unsuccessful trials with improved materials.

Impact evaluation results

The process of assessing the impact of research and extension investments involved combining farm-level information with data on research and extension costs and related economic parameters, to produce a number of quantitative indicators of profitability, efficiency, and food-security impact. This section sets the premises for estimating returns to research investments and evaluates the indicators of the impact of the investments.

Premises of the evaluation

The assessment of returns to sorghum and pearl millet research and diffusion investments were based on the following premises:

Base-level prices and production. These were computed on the basis of national agricultural statistics complemented by FAO's Agrostat data (Table 16). Since, complete regional sorghum and millet data were not available, benefits evaluation was restricted to an aggregate analysis. Base-level price and production figures are averages for the periods 1975-1978 (for generation 1 varieties) and 1986-1989 (for generation 2 varieties). This is to avoid using extreme values which may be associated with actual price and production data for a particular year.

Table 16. Area, production, and prices[1] of sorghum and pearl millet in Mali, 1975-1994.

	Sorghum			Pearl millet		
Year	Area ('000 ha)	Output ('000 t)	Price (CFA[2])	Area ('000 ha)	Output ('000 t)	Price (CFA[2])
1975	451	393	39 632	670	532	38 450
1976	570	353	37 230	844	477	39 300
1977	571	319	38 020	846	432	39 890
1978	369	387	38 360	546	523	40 890
1979	384	317	38 930	570	429	40 200
1980	446	301	39 490	660	407	39 460
1981	472	404	40 060	700	546	43 520
1982	549	449	40 630	813	608	42 200
1983	580	504	41 190	815	594	42 770
1984	387	370	41 760	910	507	43 150
1985	425	471	40 550	841	871	42 750
1986	418	465	39 010	822	806	42 100
1987	491	513	39 790	782	694	44 250
1988	679	672	41 010	1196	1000	43 930
1989	774	731	40 790	1083	842	38 180
1990	809	531	51 270	1213	737	52 000
1991	741	770	51 110	1262	890	52 020
1992	850	602	38 900	1074	582	40 680
1993	1006	694	45 340	1280	708	46 640
1994	977	746	43 300	1404	858	45 730

1. Price data are nominal producer prices from the Malian market information system (SIM) database. Since these prices do not show much variation, it was not necessary to use real prices.
2. CFA = Franc de la communante financiere Africaine.

Source: FAO Agrostat 1994; Direction de la statistique agricole, Mali, and SIM (Mali).

Farm cost structure. On the basis of the survey data, the cost structures of sorghum and millet production using traditional and improved varieties were computed and compared (Tables A-l and A-2 in Appendix A). The additional costs associated with the use of new technologies are mostly in the areas of land preparation, farmyard manure and its application, harvesting, seeds, insecticide application, and farm equipment rental. There are no additional land-preparation costs between farmers' varieties and generation 1 technologies. This additional cost concerns only generation 2 technologies which require plowing following normal land preparation. The plowing process also requires the use of animal traction, the rental of which adds to production costs.

Adoption rate projection. The sorghum and pearl millet adoption rates estimated for the survey years (1990-1995) were projected backward and forward using the logistic function (Figures 3 and 4). For the projection, adoption ceiling rates of 20% (for generation 1 sorghum and pearl millet) and 40% (for generation 2 pearl millet), and 30% (for generation 2 sorghum) were set. The rational for setting these ceiling rates is twofold: first, generation 1 pearl millet and sorghum technologies have been around for such a long time that it is believed that their adoption pattern will not rise beyond 20% before falling. As for generation 2 varieties of sorghum and pearl millet, it is believed that their early-maturity, high-yielding characteristics will help their adoption to spread and reach the 30% (for sorghum) and 40% (for pearl millet) ceiling levels by the year 2018 given the pressing need for food security in an ever demanding agroecological environment. Changing these rates significantly will require a strong political will to address major sorghum and pearl millet adoption constraints facing farmers in the country. Such political commitment is unlikely in an environment of structural adjustments characterized by government budget reduction and privatization.

Demand and supply elasticities. The economic surplus approach requires the use of supply and demand elasticity estimates. Because elasticity parameters were not available from previous studies in Mali or elsewhere in the region, initial parameter values were guessed and their validity tested through sensitivity analysis. The basis of the demand elasticity guess was the following definition; taking into account substitution effect, budget share, and income elasticity of demand:

$$E_d \approx |\sigma - p.\mu|$$

where,

E_d = elasticity of demand in absolute value;
σ = elasticity of substitution;
p = budget share; and
μ = income elasticity of demand.

For Mali, as for most Sahelian countries, the typical ranges for σ, p, and μ are: $-1 < \sigma < 0$; $0.10 < p < 0.30$; and $0.20 < \mu < 0.80$ (Masters et al. 1995). Thus, values of -0.50, +0.50, and 0.50 were set for σ, p, and μ, respectively, yielding an elasticity of demand of -0.75.

As for the assumed value for the supply elasticity of 0.40, it is based on the fact that sorghum and pearl millet in Mali remain subsistence crops produced primarily for domestic consumption even though this trend has been changing in

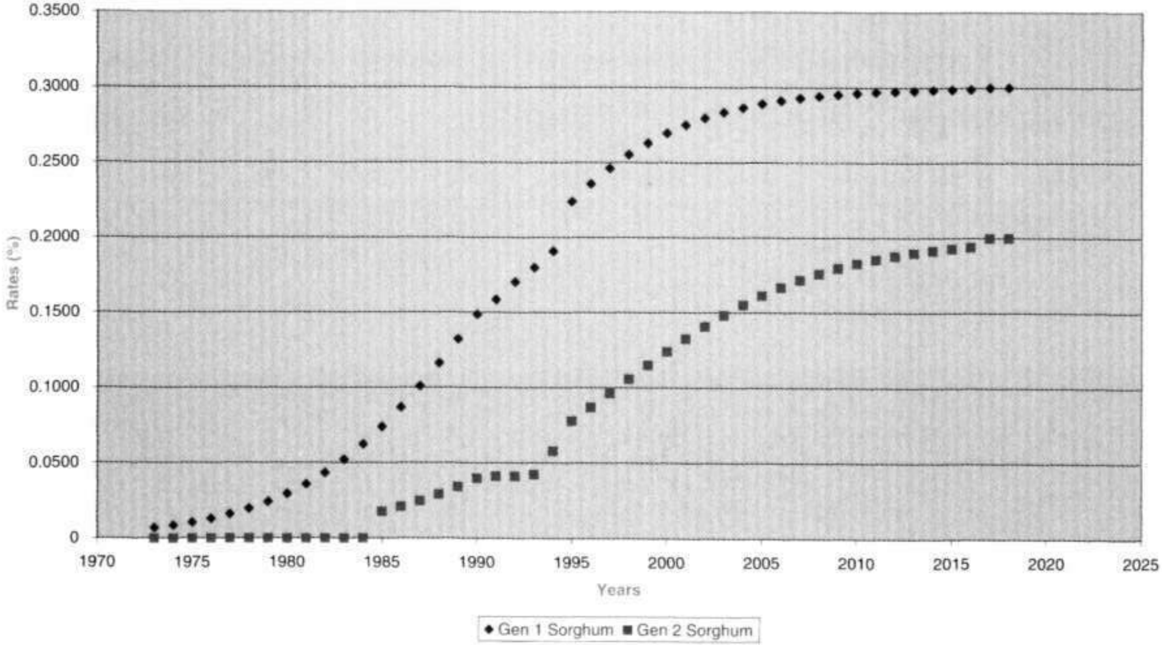

Figure 3. The logistic adoption curve for improved varieties of sorghum in Mali.

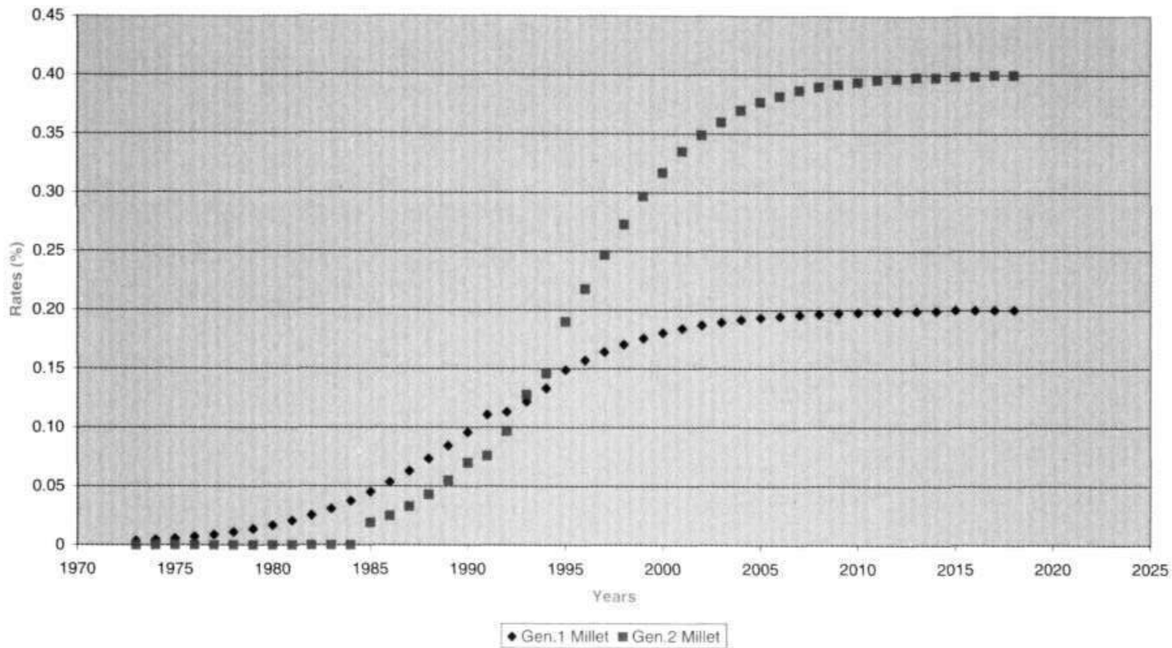

Figure 4. The logistic adoption curve for improved varieties of pearl millet in Mali.

recent years. Furthermore, current production constraints are such that supply response to output price change is unlikely to be significant, at least in the short term. The assumed elasticity values of -0.75 and 0.4 were found to be consistent with conditions typical for coarse grain demand and supply in developing environments such as those in West and Central Africa (Masters et al 1995; Yapi et al 1999).

Indicators of research impact

Three basic parameters were used as indicators of the impact of sorghum and pearl millet research in Mali. They were: food security, technical efficiency, and profitability.

Food security. The use of improved sorghum and pearl millet varieties under farmers' conditions has brought about significant yield gains to the adopting farmers. Yield advantages over local cultivars were greater for generation 2 than for generation 1 varieties (Table 17). For example, adopting farmers gained an additional 234 kg ha^{-1} using generation 1 varieties of sorghum, and 426 kg ha^{-1} by adopting generation 2 varieties (Table 17). Similarly, pearl millet farmers gained 101 kg ha^{-1} and 264 kg ha^{-1} by using generation 1 and 2 varieties, respectively. These yield gains are consistent with those reported elsewhere for Mali (Shetty et al. 1991). However, these gains should not be viewed as the impact of using improved seeds alone, but rather as the result of using these seeds within farmers' survival strategies. For example, farmers tend to cultivate improved varieties either near homesteads where household residues and farmyard manure can be easily deposited, or on newly cultivated land with good soil quality. This is part of a strategy to meet the fertilization requirements for cultivation of improved material, given the farmers' nonability to purchase commercial fertilizers for use in subsistence crops. These yields would be even greater if farmers fully adopted the recommended agronomic practices[8]. With such a boost in productivity, adopting farmers would have more access to food for their families and for social ceremonies as well as a marketable surplus. Apart from improvement in productivity, food security is also enhanced through the use of early-maturing varieties which are known to reduce risks from late-season drought and to close the hunger gap by providing the first food in the farming year.

8. Greater yield gains could potentially be secured if farmers were able to adopt the full technological package including improved seeds and accompanying management requirements. Shetty et al. (1991) have reported on station yields as high as 3000 kg ha^{-1} and 2000 kg ha^{-1}, for sorghum and pearl millet respectively in Mali under intensive farming (i.e., using commercial fertilizers at a rate of 100 kg ha^{-1} or more depending on the soil type and quality).

Table 17. Yield advantages of improved sorghum and pearl millet varieties in Mali.

Varieties	Yield (kg ha^{-1})	Yield advantage[1] (kg ha^{-1})	Increase in yield (%)
Sorghum			
Local	598	-	-
Generation 1	832	234	39
Generation 2	1024	426	71
Pearl millet			
Local	548	-	-
Generation 1	649	101	18
Generation 2	812	264	48

1. Yield advantage was calculated as the difference between an improved variety and the best local variety.
Source: Results of farm-level survey conducted by the authors.

Technical efficiency. Cost analyses of sorghum and pearl millet production indicate that by using improved cultivars farmers are able to achieve substantial reduction in the per unit cost of production. For millet, the results of the analyses show a unit production cost reduction of CFA 8706 (about US$ 17 t^{-1}) using generation 1 varieties and CFA 15 601 (about US$ 31 t^{-1}) using generation 2 technologies (Table A-l in Appendix A). For sorghum, unit production cost reductions of CFA 10 686 (about US$ 21 t^{-1}) and CFA 21 803 (about US$ 42 t^{-1}) were obtained using generation 1 and generation 2 varieties, respectively, rather than farmers' local varieties (Table A-2 in Appendix A). High-yielding improved sorghum and millet varieties therefore improve the level of technical efficiency at which farmers operate. The extent of this improvement has important implications for the extent of the financial returns and benefits to research investments.

Financial returns and benefits. The study has shown high financial returns and benefits to past investments in sorghum and pearl millet improvement research in Mali. At a 10% discount rate, and supply and demand elasticities of 0.4 and -0.75, the net present values (NPV) of the benefits of these investments were estimated at US$ 25 million for pearl millet and US$ 16 million for sorghum. These represent internal rates of returns (IRR) of 50% and 69% respectively for pearl millet and sorghum research (Tables A-3 and A-4 in Appendix A). Disaggregating the total gains into the two generations of breeding materials, one finds generational differences. For sorghum, the NPVs for generation 1 and 2 materials were US$ 7.1 million and US$ 17.5 million with IRRs of 68% and 32%, respectively (Table A-5 in Appendix A). For pearl millet, the NPVs were US$ 4.3 million for generation 1 materials and US$ 50.9 million for generation 2 materials. The IRRs were 44% and 46% respectively (Table A-5 in Appendix A). Subsequent sensitivity analyses showed that these estimates are robust, that is, they do not change significantly with variations in the parameters, except NPV which is sensitive to variations in both the discount rate and yield gains (Tables A-6a, A-6b, A-6c in Appendix A).

Three interesting observations derive from the above analytical results. The first is that a substantially lower rate of adoption of generation 2 varieties compared with generation 1 varieties (at least for sorghum) is associated with a substantially higher NPV (CFA 17.5 million vs. CFA 7.1 million). The explanation for this first observation resides in the larger reduction in unit production cost associated with the use of generation 2 technologies. Indeed, given research costs, the greater the reduction in unit production costs associated with a technology, the greater the associated benefits (NPV) will be. This actually results from the very calculation of NPV in which the stream of net benefits used depend largely on the extent of the unit production cost reduction.

The second observation is that the substantially lower NPV for generation 1 varieties compared with generation 2 varieties is associated with a substantially higher IRR, at least for sorghum (68% vs. 32%). This second observation is best explained by reference to the important relationship between IRR and the timing of technology development, release, and adoption. The shorter the time gap between research and development (R&D) of a technology and its release and adoption, the greater the returns associated with the use of that technology (Masters et al. 1995). This second observation is in fact the reflection of what happened in Mali with regard to the timing of the R&D, release and adoption of the sets of technologies under study. Indeed generation 1 varieties of sorghum and pearl millet were researched and developed from 1969-1972, and were immediately released to farmers for adoption in 1973. As for generation 2 varieties of both cultivars, their R&D started around 1977, but their release for adoption started far later in about 1985 (Table 4). The significantly shorter R&D and release gap of first generation varieties means less cost streams and more streams of benefits, leading to a larger rate of returns to the research and development investments; the opposite of this holds for the longer gap between R&D and release of generation 2 varieties.

The third observation deriving from the above analytical results has to do with the discrepancy between the NPV in the aggregate analysis and the sum of the NPVs in the disaggregated analysis [CFA 16 million vs. CFA 24.6 million (7.1 million + 17.5 million) for sorghum; and CFA 25 million vs. CFA 55.2 million (4.3 million + 50.9 million) for pearl millet]. This result is possible and finds its explanation in the fact that the aggregation process dilutes the strength of both the yield gain and unit production cost reduction effect of generation 2 varieties, whereby reducing the streams of annual gains to the research and development investments.

Summary of gains from research

The returns to research in terms of food security, technical efficiency, and profitability are summarized for sorghum and pearl millet improved varieties emanating from the two breeding philosophies (Table A-5 in Appendix A). On aggregate (i.e., both generations together), sorghum research returns a yield gain of 330 kg ha^{-1}, a unit cost redaction of CFA 16, an NPV of US$ 16.4 million, and an IRR of 69%. Most of the gains to sorghum research were contributed by materials from generation 2, corresponding to 426 kg ha^{-1} in yield gain, CFA 22 kg^{-1} cost reduction, and an NPV of US$ 17.5 million.

Similarly for pearl millet, aggregating all the improved varieties returns a yield gain of 183 kg ha^{-1}, a unit cost reduction of CFA 12 kg^{-1}, an NPV of US$ 25 million, and an IRR of 50%. As with sorghum, generation 2 materials contributed the most to the returns from adopting improved pearl millet varieties.

Conclusions and implications

This study has demonstrated that past investments in sorghum and pearl millet improvement research and extension in Mali have been highly successful. With estimated NPV and IRR as high as US$ 25 million and 50% for pearl millet and US$ 16 million and 69% for sorghum, these investments have been highly profitable compared with any other investment alternative in the public sector. An important lesson from the disaggregated analyses is that the shorter the time gap between research and development, release, and adoption of the technology, the greater the returns to the research and development investments of the technology. Important technologies were developed as a result of research, some of which were adopted by farmers to a significant degree. Three major farm-level impact indicators have been identified: (1) production increased significantly when farmers adopted improved sorghum and millet cultivars, leading to a reduction in the unit cost of production; (2) farmers increased their food security by producing more food as well as generating a marketable surplus; and (3) farmers became more efficient in their use of basic inputs such as labor and land. Such increased returns to land and labor are important in improving subsistence farmers' revenues. For example, the higher productivity frees land and labor which can then be invested in alternative enterprises, thereby diversifying sources of income.

Farm-level impacts were clearly greater for generation 2 than for generation 1 varieties. For example, the average yield advantages associated with generation 1 varieties were estimated at 39% for sorghum and 18% for pearl millet while for generation 2 varieties, these were as high as 71% for sorghum and 48% for pearl millet. The associated reductions in unit costs of production of pearl millet were about CFA 9 kg^{-1} for generation 1 and CFA 16 kg^{-1} for generation 2 varieties. For sorghum varieties, the reductions in unit costs of production were estimated at CFA 11 kg^{-1} for generation 1 and CFA 22 kg^{-1} for generation 2. Nevertheless, farmers tend to prefer generation 1 varieties over generation 2 varieties. This preference is explained by the following three reasons: (1) farmers are more familiar with generation 1 varieties than generation 2 varieties (the former being improved versions of farmers' traditional varieties); (2) generation 2 varieties of sorghum and pearl millet are more demanding in terms of soil fertilization, seed purity, and agronomic practices; (3) the farming environment in most of the research sites remains traditional (labor-intensive production systems, most farmers are small and poor), with little or no improvement to allow greater adoption of generation 2 varieties despite their higher productivity.

Farmers' reaction to the new varieties developed with exotic germplasm raise two fundamendal questions: (1) Should we be more concerned with productivity gains than adoption rates? (2) Should we continue to develop new technologies for use in old farming environments? The answers to these questions are crucial for achieving greater impact with agricultural research in Mali.

Greater productivity vs higher adoption rates. The drive for greater productivity in developing agricultural technologies for Africa seems to be well justified in a continent prone to hunger. Yet, the results of this study show a higher preference by farmers for improved local varieties than for high-yielding new varieties developed with exotic germplasm. Does this imply that we should be more concerned with adoption rates than productivity gains? We need to be more careful here in assessing the situation. First we need to realize that the exotic varieties have not been completely rejected, but adopted to quite a significant degree by a selected class of farmers who unfortunately, do not show clear distinctive characteristics.

Second, we should recognize the constraints cited by nonadopters and see whether their resolution would improve adoption. High seed costs and increased fertilization are but some of the factors limiting the adoption of exotic varieties. Clearly, until we remove these constraints, we will never know where our concerns should really be.

Should we continue to develop new technologies for use in old farming environments? The results of this study seem to indicate that there is no real need for breeders if all that is wanted is to develop high-yielding, early-maturing varieties for use under the same old traditional practices of the average African farmer. Unless farmers' traditional conditions are changed significantly, high-input improved varieties developed through plant breeding may not be widely adopted; and it would be wise to again emphasize the earlier approach of collecting, testing, purifying, and offering to farmers the local landrace varieties which fit well into the traditional farming environment and with which small farmers are familiar.

Nevertheless, emerging changes in the socioeconomic environment of West African countries must be noted. The recent devaluation of the CFA and market liberalization as major structural adjustment initiatives are examples of such changes. With these changes comes a greater demand for domestic materials for processing in the brewery, feedstock, and bakery industries. These new developments, if sustained, may create ready markets for farmers, providing them with the incentive to move beyond subsistence production into market production. This niche can be satisfied by emphasizing high-yielding and high-input cultivars.

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APPENDIX A

Table A-1. Production cost structure (ha^{-1} year^{-1}) for local and improved sorghum varieties in Mali.

Inputs	Unit	Unit price (CFA)	Quantity[1] (local)	Cost (local)	Quantity[2] (gen.1)	Cost (gen. 1)	Quantity[2] (gen. 2)	Cost (gen.2)	Quantity[2] (all gen.)	Cost (all gen.)
Variable costs										
Labor										
• Field preparation	Days	500	11.12	5 559	12.18	6 092	10.38	5 192	11.28	5 642
• Plowing	Days	500	0.00	0	0.00	0	8.23	4 113	4.11	2 057
• FYM application	Days	500	11.00	5 501	14.50	7 248	13.79	6 897	14.14	7 073
• Sowing	Days	500	8.86	4 432	10.25	5 123	11.06	5 530	10.65	5 326
• Resowing	Days	500	1.51	756	2.23	1 117	2.50	1 252	2.37	1 184
• Weeding no. 1	Days	500	17.00	8 499	18.40	9 198	13.29	6 646	15.84	7 922
• Weeding no. 2	Days	500	15.88	7 941	17.35	8 676	12.53	6 263	14.94	7 470
• Weeding no. 3	Days	500	0.00	0	0.00	0	0.00	0	0	0
• Harvesting	Days	500	7.30	3 652	9.64	4 821	9.29	4 647	9.47	4 733
• Threshing	Days	500	4.81	2 406	5.75	2 873	6.71	3 353	6.23	3 113
• Hauling	Days	500	2.38	1 189	3.36	1 681	4.06	2 028	3.71	1 854
Seeds	Kg	45	8.83	397	10.00	550	10.45	679	10.22	615
Insecticides	Kg	240	1.10	264	2.64	633	3.28	786	2.96	710
Farmyard manure	Cartload	660	9.67	5 800	12.06	7 234	14.83	8 895	13.44	8 064
Chemical fertilizer	Kg	230	0.00	0	0.00	0	0.00	0	0	0
Equipment rental	Days	1 000	1.10	1 100	1.97	1 972	2.73	2 725	2.35	2 349
Total variable costs	CFA ha^{-1}			47 496		57 219		59 005		58 112
Output ha^{-1} year^{-1}	Kg ha^{-1}			597.94		832.33		1023.87		928.10
Unit variable cost	CFA kg^{-1}			79.43		68.75		57.63		63.19
Unit variable cost reduction	CFA kg^{-1}					10.68		21.80		16.24

1. Without research.
2. With research.

Table A-2. Production cost structure (ha^{-1} year^{-1}) for local and improved pearl millet varieties in Mali.

Inputs	Unit	Unit price (CFA)	Quantity[1] (local)	Cost (local)	Quantity[2] (gen.1)	Cost (gen. 1)	Quantity[2] (gen. 2)	Cost (gen.2)	Quantity[2] (all gen.)	Cost (all gen.)
Variable costs										
Labor										
Field preparation	Days	500	9.66	4 830	9.88	4 941	11.99	5 996	10.94	5 469
Plowing	Days	500	0.00	0	0.00	0	11.66	5 828	5.83	2 914
FYM application	Days	500	15.06	7 529	16.38	8 190	18.68	9 339	17.53	8 764
Sowing	Days	500	12.08	6 041	12.35	6 176	11.58	5 789	11.96	5 983
Resowing	Days	500	2.42	1 212	1.56	778	0.65	326	1.10	552
Weeding no. 1	Days	500	16.98	8 492	16.65	8 324	12.21	6 104	14.43	7 214
Weeding no. 2	Days	500	15.35	7 677	14.59	7 293	11.76	5 882	13.17	6 587
Weeding no. 3	Days	500	0.00	0	0.00	0	0.08	41	0.04	20
Harvesting	Days	500	9.82	4 910	11.21	5 606	10.90	5 451	11.05	5 528
Threshing	Days	500	4.29	2 146	4.50	2 248	5.70	2 850	5.09	2 549
Hauling	Days	500	3.31	1 653	3.60	1 799	4.86	2 432	4.23	2 115
Seeds	Kg	45	8.73	393	10.00	550	10.32	671	10.16	611
Insecticides	Kg	240	1.15	276	2.75	660	4.36	1 046	3.55	853
Farmyard manure	Cartload	600	9.57	5 740	11.95	7 168	14.75	8 852	13.35	8 010
Chemical fertilizer	Kg	230	0.00	0	0.00	0	0.52	120	0.26	60
Equipment rental	Days	1000	1.17	1 167	2.31	2 307	3.78	3 780	3.04	3 043
Total variable costs	CFA			52 064		56 040		64 508		60 273
Output ha^{-1} year^{-1}	Kg ha^{-1}			547.50		648.70		811.50		730.10
Yield advantage	Kg ha^{-1}			95.09	0.18	86.39	0.48		0.33	
Unit variable cost	CFA kg^{-1}							79.49		82.94
Unit variable cost reduction	CFA kg^{-1}					8.71		15.60		12.15

1. Without research.
2. With research.

Table A-3. Benefit assessment of sorghum improvement research in Mali.

Year	Research costs				Research gains (US$)	Net benefits (US$)	Adoption level				Annual gains			Gains to consumers		Gains to producers	
	IER	ICRISAT	PNVA	Total			Gen 0	Gen 1	Gen 2	Total	Gen 1	Gen 2	Total gains	Total	%	Total	%
Present value	275,690	1,691,777		1,347,318	26,086,435	16,470,069					12,420,460	20,008,354	322,246,064	5,609,737		6,231,611	
Total value	1124320	4154000		6548320	192846910	413697311					82427628	110419281	1547873696	39305948		43663254	
1969	17,500	0	0	17,500	0	- 17,500	1.0000	0	0	0	0	0	0	0	34.78	47,381	38.64
1970	17,500	0	0	17,500	0	- 17,500	1.0000	0	0	0	0	0	0	0	34.78	58,529	38.64
1971	17,500	0	0	17,500	0	- 17,500	1.0000	0	0	0	0	0	0	0	34.78	72,464	38.64
1972	17,500	0	0	17,500	0	- 17,500	1.0000	0	0	0	0	0	0	0	34.78	89,884	38.64
1973	17,500	0	27,000	44,500	122,625	78,125	0.9932	0.0068	0	0.0068	122,625	0	18,033,129	42,652	34.78	47,381	38.64
1974	17,500	0	27,000	44,500	151,478	106,978	0.9916	0.0084	0	0.0084	151,478	0	18,033,129	52,688	34.78	58,529	38.64
1975	17,500	0	27,000	44,500	187,545	143,045	0.9896	0.0104	0	0.0104	187,545	0	18,033,129	65,233	34.78	72,464	38.64
1976	32,331	0	45,500	77,831	232,627	154,796	0.9871	0.0129	0	0.0129	232,627	0	18,033,129	80,914	34.78	89,884	38.64
1977	32,331	40,500	45,500	118,331	286,727	168,396	0.9841	0.0159	0	0.0159	286,727	0	18,033,129	99,731	34.78	110,787	38.64
1978	32,331	40,500	45,500	118,331	353,449	235,118	0.9804	0.0196	0	0.0196	353,449	0	18,033,129	122,939	34.78	136,567	38.64
1979	32,331	105,500	45,500	183,331	434,598	251,267	0.9759	0.0241	0	0.0241	434,598	0	18,033,129	151,165	34.78	167,922	38.64
1980	32,331	107,500	45,500	185,331	530,174	344,843	0.9706	0.0294	0	0.0294	530,174	0	18,033,129	184,408	34.78	204,851	38.64
1981	32,331	104,500	45,500	182,331	645,586	463,255	0.9642	0.0358	0	0.0358	645,586	0	18,033,129	224,552	34.78	249,445	38.64
1982	32,331	374,500	45,500	452,331	780,834	328,503	0.9576	0.0433	0	0.0433	780,834	0	18,033,129	271,595	34.78	301,703	38.64
1983	57,731	347,500	64,500	469,731	939,526	469,795	0.9479	0.0521	0	0.0521	939,526	0	18,033,129	326,792	34.78	363,019	38.64
1984	57,731	347,500	64,500	469,731	1,123,464	653,733	0.9377	0.0623	0	0.0623	1,123,464	0	18,033,129	390,770	34.78	434,089	38.64
1985	57,731	347,500	64,500	469,731	2,491,803	2,022,072	0.9083	0.0739	0.018	0.0917	1,332,648	1,159,155	65,121,067	575,178	23.08	638,940	25.64
1986	57,731	347,500	64,500	469,731	2,939,330	2,469,599	0.8921	0.0868	0.021	0.1079	1,565,276	1,374,055	65,121,067	676,791	23.03	751,818	25.58
1987	57,731	347,500	64,500	499,231	3,441,057	2,941,826	0.8742	0.1019	0.025	0.1255	1,819,543	1,621,515	65,121,067	789,067	22.93	876,540	25.47
1988	57,731	383,500	64,500	505,731	4,003,497	3,497,766	0.8545	0.1162	0.029	0.1455	2,095,450	1,908,047	65,121,067	812,633	22.80	1,013,804	25.32
1989	57,731	370,750	64,500	492,981	4,615,829	4,122,848	0.8336	0.1321	0.034	0.1664	2,382,176	2,233,653	65,121,067	1,043,726	22.61	1,159,430	25.12
1990	57,731	378,250	64,500	500,481	5,284,566	4,784,085	0.8114	0.1486	0.040	0.1686	2,679,723	2,604,843	65,121,067	1,182,973	22.39	1,314,113	24.87
1991	57,731	380,250	64,500	502,481	5,554,263	5,051,782	0.8001	0.1585	0.041	0.1999	2,858,251	2,696,012	65,121,067	1,253,851	22.57	1,392,848	25.08
1992	57,731	20,250	64,500	142,481	5,767,054	5,624,573	0.7883	0.1703	0.041	0.2117	3,071,042	2,696,012	65,121,067	1,327,866	23.03	1,475,068	25.58

Continued

Table A-3. *Continued*

Year	Research costs				Research gains (US$)	Net benefits (US$)	Adoption level				Annual gains			Gains to consumers		Gains to producers	
	IER	ICRISAT	PNVA	Total			Gen 0	Gen 1	Gen 2	Total	Gen 1	Gen 2	Total gains	Total	%	Total	%
1993	57,731	20,250	64,500	142,481	6,010,002	5,867,521	0.7777	0.2223	0.043	0.1798	3,242,357	2,767,645	65,121,067	1,394,353	23.20	1,548,925	25.77
1994	57,731	20,250	64,500	142,481	7,217,743	7,075,262	0.7512	0.2488	0.058	0.1908	3,440,721	3,777,022	65,121,067	1,560,571	21.62	1,733,570	24.02
1995	57,731	20,250	64,500	142,481	9,118,864	8,976,383	0.6980	0.3020	0.078	0.2240	4,039,421	5,079,443	65,121,067	1,894,263	20.77	2,104,253	23.08
1996	25,250	20,250	32,000	77,250	9,924,257	9,847,007	0.6771	0.3229	0.087	0.2358	4,252,212	5,672,045	65,121,067	2,025,356	20.41	2,249,879	22.67
1997	0	0	0	0	10,717,427	10,717,427	0.6574	0.3426	0.096	0.2462	4,439,756	6,277,671	65,121,067	2,148,922	20.05	2,387,143	22.27
1998	0	0	0	0	11,491,863	11,491,863	0.6390	0.3610	0.106	0.2552	4,602,054	6,889,809	65,121,067	2,264,334	19.70	2,515,349	21.89
1999	0	0	0	0	12,236,344	12,236,344	0.6220	0.3780	0.115	0.2629	4,740,910	7,495,435	65,121,067	2,370,964	19.38	2,633,800	21.52
2000	0	0	0	0	12,941,453	12,941,453	0.6064	0.3936	0.124	0.2695	4,859,928	8,081,524	65,121,067	2,468,814	19.08	2,742,497	21.19
2001	0	0	0	0	13,600,676	13,600,676	0.5923	0.4077	0.133	0.2750	4,959,110	8,641,566	65,121,067	2,557,254	18.80	2,840,742	20.89
2002	0	0	0	0	14,211,109	14,211,109	0.5796	0.4204	0.141	0.2796	5,042,063	9,169,046	65,121,067	2,636,914	18.56	2,929,232	20.61
2003	0	0	0	0	14,768,043	14,768,043	0.5683	0.4317	0.148	0.2834	5,110,589	9,657,454	65,121,067	2,707,792	18.34	3,007,967	20.37
2004	0	0	0	0	15,273,281	15,273,281	0.5583	0.4417	0.155	0.2865	5,166,491	10,106,790	65,121,067	2,770,516	18.14	3,077,644	20.15
2005	0	0	0	0	15,723,918	15,723,918	0.5495	0.4505	0.161	0.2891	5,213,378	10,510,540	65,121,067	2,825,713	17.97	3,138,960	19.96
2006	0	0	0	0	16,119,953	16,119,953	0.5419	0.4581	0.167	0.2912	5,251,247	10,868,706	65,121,067	2,873,383	17.83	3,191,915	19.80
2007	0	0	0	0	16,469,703	16,469,703	0.5353	0.4647	0.172	0.2929	5,281,903	11,187,799	65,121,067	2,914,781	17.70	3,237,902	19.66
2008	0	0	0	0	16,766,654	16,766,654	0.5298	0.4702	0.176	0.2942	5,305,346	11,461,308	65,121,067	2,949,279	17.59	3,276,225	19.54
2009	0	0	0	0	17,027,439	17,027,439	0.5250	0.4750	0.180	0.2953	5,325,183	11,702,256	65,121,067	2,979,386	17.50	3,309,670	19.44
2010	0	0	0	0	17,252,056	17,252,056	0.5209	0.4791	0.183	0.2962	5,341,413	11,910,643	65,121,067	3,005,103	17.42	3,338,237	19.35
2011	0	0	0	0	17,442,309	17,442,309	0.5174	0.4826	0.186	0.2970	5,355,839	12,086,470	65,121,067	3,027,057	17.35	3,362,624	19.28
2012	0	0	0	0	17,601,104	17,601,104	0.5146	0.4854	0.188	0.2975	5,364,856	12,236,248	65,121,067	3,044,619	17.30	3,382,134	19.22
2013	0	0	0	0	17,746,875	17,746,875	0.5120	0.4880	0.190	0.2980	5,373,872	12,373,003	65,121,067	3,060,928	17.25	3,400,250	19.16
2014	0	0	0	0	17,851,770	17,851,770	0.5101	0.4899	0.192	0.2984	5,381,086	12,470,684	65,121,067	3,072,845	17.21	3,413,489	19.12
2015	0	0	0	0	17,948,349	17,948,349	0.5084	0.4916	0.193	0.2987	5,386,496	12,561,854	65,121,067	3,083,508	17.18	3,425,334	19.08
2016	0	0	0	0	18,030,101	18,030,101	0.5070	0.4930	0.194	0.2989	5,390,102	12,639,999	65,121,067	3,092,290	17.15	3,435,089	19.05
2017	0	0	0	0	18,434,152	18,434,152	0.5000	0.5000	0.200	0.3000	5,409,939	13,024,213	65,121,067	3,136,196	17.01	3,483,863	18.90
2018	0	0	0	0	18,434,152	18,434,152	0.5000	0.5000	0.200	0.3000	5,409,939	13,024,213	65,121,067	3,136,196	17.01	3,483,863	18.90

1. Internal rates of return = 0.6907.

Table A-4. Benefit assessment of pearl millet improvement research in Mali.

	Research costs				Research gains	Net benefits	Adoption level				Annual gains			Gains to consumers		Gains to producers	
Year	IER	ICRISAT	PNVA	Total	(US$)	(US$)	Gen 0	Gen 1	Gen 2	Total	Gen 1	Gen 2	Total gains	Total	%	Total	%
Present value	290,897	1,718,180		1,394,305	38,698,806	25,084,487					8,362,843	44,414,883	330,207,059	5,709,641		6,046,234	
Total value	1,674,320	4,599,500		8,247,820	321213583	698,883305					57118897	264094686	1568522197	46387478		49122094	
1969	17,500	0	0	17,500	0	- 17,500	1.0000	0	0	0	0	0	0	0		0	
1970	17,500	0	0	17,500	0	- 17,500	1.0000	0	0	0	0	0	0	0		0	
1971	17,500	0	0	17,500	0	- 17,500	1.0000	0	0	0	0	0	0	0		0	
1972	17,500	0	0	17,500	0	- 17,500	1.0000	0	0	0	0	0	0	0		0	
1973	17,500	0	27,000	44,500	66,351	21,851	0.9965	0.0035	0	0.0035	66,351	0	18,957,483	23,079	34.78	24,439	36.83
1974	17,500	0	27,000	44,500	85,309	40,809	0.9955	0.0045	0	0.0045	85,309	0	18,957,483	29,673	34.78	31,422	36.83
1975	17,500	0	27,000	44,500	106,162	61,662	0.9944	0.0056	0	0.0056	106,162	0	18,957,483	36,926	34.78	39,103	36.83
1976	32,331	0	45,500	77,831	132,702	54,871	0.9930	0.0070	0	0.0070	132,702	0	18,957,483	46,157	34.78	48,878	36.83
1977	32,331	40,500	45,500	118,331	164,930	46,599	0.9913	0.0087	0	0.0087	164,930	0	18,957,483	57,367	34.78	60,749	36.83
1978	32,331	40,500	45,500	118,331	206,637	88,306	0.9891	0.0109	0	0.0109	206,637	0	18,957,483	71,874	34.78	76,111	36.83
1979	32,331	105,500	45,500	183,331	255,926	72,595	0.9865	0.0135	0	0.0135	255,926	0	18,957,483	89,018	34.78	94,265	36.83
1980	32,331	107,500	45,500	185,331	316,590	131,259	0.9833	0.0167	0	0.0167	316,590	0	18,957,483	110,118	34.78	116,610	36.83
1981	32,331	104,500	45,500	182,331	390,524	208,193	0.9794	0.0206	0	0.0206	390,524	0	18,957,483	135,834	34.78	143,842	36.83
1982	32,331	374,500	45,500	452,331	479,624	27,293	0.9747	0.0253	0	0.0253	479,624	0	18,957,483	166,826	34.78	176,661	36.83
1983	57,731	347,500	64,500	469,731	583,890	114,159	0.9692	0.0308	0	0.0308	583,890	0	18,957,483	203,092	34.78	215,065	36.83
1984	57,731	347,500	64,500	469,731	709,010	239,279	0.9626	0.0374	0	0.0374	709,010	0	18,957,483	246,612	34.78	261,150	36.83
1985	57,731	347,500	64,500	469,731	2,098,810	1,629,079	0.9361	0.0449	0.019	0.0639	851,191	1,247,619	65,664,160	421,351	20.08	446,190	21.26
1986	57,731	347,500	64,500	469,731	2,653,934	2,184,203	0.9216	0.0534	0.025	0.0784	1,012,330	1,641,604	65,664,160	516,962	19.48	547,438	20.63
1987	57,731	347,500	64,500	499,231	3,339,644	2,840,413	0.9044	0.0629	0.033	0.0956	1,192,426	2,147,218	65,664,160	630,378	18.87	667,539	19.98
1988	57,731	383,500	64,500	505,731	4,180,310	3,674,579	0.8842	0.0733	0.043	0.1158	1,389,584	2,790,727	65,664,160	763,574	18.26	808,588	19.34
1989	57,731	370,750	64,500	492,981	5,196,512	4,703,531	0.8609	0.0843	0.055	0.1391	1,814,231	3,598,396	65,664,160	917,212	17.65	971,284	18.69
1990	57,731	378,250	64,500	500,481	6,410,722	5,910,241	0.8343	0.0957	0.070	0.1657	2,100,489	4,596,491	65,664,160	1,092,610	17.34	1,157,022	18.05
1991	57,731	380,250	64,500	502,481	7,090,969	6,588,484	0.8132	0.1108	0.076	0.1868	2,145,987	4,990,476	65,664,160	1,231,742	17.37	1,304,355	18.39
1992	57,731	20,250	64,500	142,481	8,495,711	8,353,230	0.7901	0.1132	0.097	0.2099	2,310,917	6,349,724	65,664,160	1,384,061	16.29	1,465,654	17.25
1993	57,731	20,250	64,500	142,481	10,735,629	10,593,148	0.7498	0.1219	0.128	0.2502	2,525,137	8,424,712	65,664,160	1,649,796	15.37	1,747,054	16.27
1994	57,731	20,250	64,500	142,481	12,098,971	11,956,490	0.7210	0.1332	0.146	0.2790	2,820,874	9,573,835	65,664,160	1,839,700	15.20	1,948,153	16.10
1995	57,731	20,250	64,500	142,481	15,270,798	15,128,317	0.6616	0.1488	0.190	0.3384	2,978,221	12,449,925	65,664,160	2,231,378	14.61	2,362,922	15.47
1996	25,250	20,250	32,000	77,250	17,319,273	17,242,023	0.6245	0.1571	0.218	0.3755	3,114,715	14,341,053	65,664,160	2,476,012	14.29	2,621,977	15.14
1997	0	0	0	0	19,300,930	19,303,930	0.5892	0.1643	0.247	0.4108	3,234,147	16,186,215	65,664,160	2,708,777	14.03	2,868,464	14.86
1998	0	0	0	0	21,147,330	21,147,330	0.5566	0.1706	0.273	0.4434	3,334,621	17,913,183	65,664,160	2,923,738	13.83	3,096,098	14.64
1999	0	0	0	0	22,804,045	22,804,045	0.5276	0.1759	0.297	0.4724	3,419,930	19,469,423	65,664,160	3,114,962	13.66	3,298,594	14.46
2000	0	0	0	0	24,242,035	24,242,035	0.5025	0.1804	0.317	0.4975	3,490,073	20,822,105	65,664,160	3,280,469	13.53	3,473,858	14.33

Continued

Table A-4. *Continued*

Year	Research costs				Research gains (US$)	Net benefits (US$)	Adoption level				Annual gains			Gains to consumers		Gains to producers	
	IER	ICRISAT	PNVA	Total			Gen 0	Gen 1	Gen 2	Total	Gen 1	Gen 2	Total gains	Total	%	Total	%
2001	0	0	0	0	25,454,734	25,454,734	0.4814	0.1841	0.335	0.5186	3,546,945	21,964,662	65,664,160	3,419,600	13.43	3,621,191	14.22
2002	0	0	0	0	26,457,171	26,457,171	0.4640	0.1871	0.349	0.5360	3,594,339	22,910,225	65,664,160	3,534,334	13.40	3,742,689	14.15
2003	0	0	0	0	27,259,702	27,259,702	0.4500	0.1896	0.360	0.5500	3,634,150	23,665,363	65,664,160	3,626,649	13.30	3,840,446	14.09
2004	0	0	0	0	27,903,623	27,903,623	0.4387	0.1917	0.370	0.5613	3,664,482	24,269,474	65,664,160	3,701,160	13.26	3,919,349	14.05
2005	0	0	0	0	28,406,737	28,406,737	0.4299	0.1933	0.377	0.5701	3,689,126	24,742,256	65,664,160	3,759,187	13.23	3,980,797	14.01
2006	0	0	0	0	28,792,535	28,792,535	0.4231	0.1946	0.382	0.5769	3,709,979	25,103,408	65,664,160	3,804,025	13.21	4,028,278	13.99
2007	0	0	0	0	29,095,744	29,095,744	0.4177	0.1957	0.387	0.5823	3,727,041	25,385,764	65,664,160	3,839,632	13.20	4,065,985	13.97
2008	0	0	0	0	29,329,497	29,329,497	0.4135	0.1966	0.390	0.5865	3,740,311	25,602,456	65,664,160	3,867,327	13.18	4,095,312	13.96
2009	0	0	0	0	29,506,928	29,506,928	0.4103	0.1973	0.392	0.5897	3,749,790	25,766,616	65,664,160	3,888,427	13.18	4,117,656	13.95
2010	0	0	0	0	29,634,602	29,634,602	0.4080	0.1978	0.394	0.5920	3,757,373	25,884,812	65,664,160	3,903,593	13.17	4,133,716	13.95
2011	0	0	0	0	29,740,681	29,740,681	0.4061	0.1982	0.396	0.5939	3,764,956	25,983,308	65,664,160	3,916,122	13.16	4,146,983	13.94
2012	0	0	0	0	29,813,929	29,813,929	0.4047	0.1986	0.397	0.5953	3,770,643	26,048,972	65,664,160	3,925,353	13.16	4,156,759	13.94
2013	0	0	0	0	29,872,147	29,872,147	0.4036	0.1989	0.398	0.5964	3,774,435	26,101,504	65,664,160	3,932,606	13.16	4,164,440	13.94
2014	0	0	0	0	29,915,337	29,915,337	0.4028	0.1991	0.398	0.5972	3,791,497	26,140,902	65,664,160	3,937,881	13.16	4,170,026	13.94
2015	0	0	0	0	29,965,231	29,965,231	0.4014	0.2000	0.399	0.5986	3,791,497	26,173,734	65,664,160	3,947,113	13.17	4,179,801	13.95
2016	0	0	0	0	29,984,930	29,984,930	0.4011	0.2000	0.399	0.5989	3,791,497	26,193,433	65,664,160	3,949,091	13.17	4,181,896	13.95
2017	0	0	0	0	30,057,161	30,057,161	0.4000	0.2000	0.400	0.6000	3,791,497	26,265,664	65,664,160	3,956,344	13.16	4,189,577	13.94
2018	0	0	0	0	30,057,161	30,057,161	0.4000	0.2000	0.400	0.6000	3,791,497	26,265,664	65,664,160	3,956,344	13.16	4,189,577	13.94

1. Internal rate of return (IRR) = 0.5028 .

Table A-5. Summary of indicators of impact of sorghum and pearl millet research in Mali[1].

Varieties	Food security		Technical efficiency			Profitability	
	Yield ($kg\ ha^{-1}$)	Yield gain ($kg\ ha^{-1}$)	Variable costs ($CFA\ ha^{-1}$)	Unit variable cost ($CFA\ kg^{-1}$)	Unit cost reduction ($CFA\ kg^{-1}$)	Net present value (Million US$)	Internal rate of returns (%)
Sorghum							
Local varieties	598	–	47 496	79.43	–	–	–
Improved varieties (all generations)	928	330	58 112	63.19	16	16.4	69
Generation 1 varieties	832	234	57 219	68.75	11	7.1	68
Generation 2 varieties	1024	426	59 005	57.63	22	17.5	32
Pearl Millet							
Local varieties	548	–	52 064	95.09	–	–	–
Improved varieties (all generations)	730	182	60 274	82.94	12	25.0	50
Generation 1 varieties	649	101	56 040	86.38	9	4.3	44
Generation 2 varieties	812	264	64 500	79.49	16	50.9	46

1. Yield gain and cost estimates are based on farm-level survey data. Computation of NPV and IRR estimates covers the period from 1969 (when research on generation 1 varieties started) to 2018 (horizon).

Table A-6a. Sensitivity analyses of the demand and supply elasticities and the discount rate.

	Benefit indicators of sorghum		Benefit indicators of pearl millet	
Alternative values of demand elasticity	NPV (million US$)	IRR (%)	NPV (million US$)	IRR (%)
0.85	16.51	69.15	25.14	50.32
0.80	16.49	69.11	25.11	50.30
0.75	16.47	69.07	25.08	50.28
0.70	16.44	69.03	25.05	50.25
0.65	16.41	68.98	25.01	50.22
Alternative values of supply elasticity	NPV (million US$)	IRR (%)	NPV (million US$)	IRR (%)
0.50	16.63	69.35	25.28	50.44
0.45	16.55	69.22	25.18	50.36
0.40	16.47	69.07	25.08	50.28
0.35	16.37	68.91	24.97	50.19
0.30	16.27	68.74	24.85	50.09
Alternative values of discount rate	NPV (million US$)	IRR (%)	NPV (million US$)	IRR (%)
0.15	4.79	69.07	6.52	50.28
0.12	9.78	69.07	14.31	50.28
0.10	16.47	69.07	25.08	50.28
0.08	28.82	69.07	45.40	50.28
0.05	72.14	69.07	118.05	50.28

Table A-6b. Sensitivity analyses of sorghum yield gains (best locals versus improved varieties).

Average yield of local sorghum varieties (kg ha^{-1}) A	Alternative values of generation 1 sorghum yield (kg ha^{-1}) B	Alternative sorghum yield gain[1] values (kg ha^{-1}) B-A	NPV (million US$)	IRR (%)
598	850	252	8.19	74
598	832	234	7.13	68
598	727	129	0.03	10
598	726	128	-0.03	

Average yield of local sorghum varieties (kg ha^{-1}) A	Alternative values of generation 2 sorghum yield (kg ha^{-1}) B	Alternative sorghum yield gain[1] values (kg ha^{-1}) B-A	NPV (million US$)	IRR (%)
598	1040	442	18.30	33
598	1024	426	17.47	32
598	759	161	0.02	10
598	758	160	-0.06	-

1. Yield gains/advantages are computed as yield differential between improved and local varieties.

Table A-6c. Sensitivity analyses of pearl millet yield gains (best locals versus improved varieties).

Average yield of local millet (kg ha^{-1}) A	Alternative values of generation 1 pearl millet yield (kg ha^{-1}) B	Millet yield gain[1] values (kg ha^{-1}) :local vs generation 1 B-A	NPV (million US$)	IRR (%)
548	660	112	5.26	51
548	649	101	4.32	45
548	602	54	0.15	11
548	600	52	-0.03	9

Average yield of local millet (kg ha^{1}) A	Alternative values of generation 2 pearl millet yield (kg ha^{-1}) B	Millet yield gain[1] values (kg ha^{-1}): local vs generation 2 B-A	NPV (million US$)	IRR (%)
548	820	272	53.52	47
548	812	264	50.80	46
548	674	126	0.09	10
548	673	125	-0.32	-

1. Yield gains/advantages were computed as the yield differential between improved and local varieties.

Notes

List of publications in this series

Bantilan, M.C.S., and Joshi, P.K. 1996. Returns to research and diffusion investments on wilt resistance in pigeonpea. (In En. Summaries in En, Fr.) Impact Series no. 1. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 36 pp. ISBN 92-9066-356-1. Order code ISE 001.

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