Impact Series no. 6

Assessment of the Economic Impact of Sorghum Variety S 35 in Chad

International Crops Research Institute for the Semi-Arid Tropics

Citation: Yapi, A.M., Dehala, G., Ngawara, K., and Issaka, A. 1999. Assessment of the economic impact of sorghum variety S 35 in Chad. (In En. Summaries in En, Fr.) Impact Series no. 6. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 34 pp. ISBN 92-9066-408-8. Order code ISE 006.

Abstract

The S 35 sorghum variety is a nonphotoperiod-sensitive, high-yielding, early-maturing, and drought-tolerant pure line that originated from ICRISAT's breeding program in India, and was later advanced and promoted in Cameroon and Chad. Its introduction into drought-prone areas of Chad has been very successful with a net present value of research investments estimated at US$ 15 million, representing an internal rate of return of 95%. Two crucial factors explain this apparent success: (1) germplasm research spillovers from ICRISAT and Cameroon's breeding programs substantially reduced the time lag in S 35 research and development in Chad; and (2) the FAO/UNDP-supported seed project at Gassi not only successfully multiplied S 35 seed on a large scale, but also distributed it to farmers by adopting the 'mini-doses' approach and involving the Office national de developpement rural and NGOs.

Since the recommended management practices for S 35 adoption are simple, relatively easy to implement with available family labor and animal traction, and are not capital intensive, the technology has found favor with many farmers. Between 1990 and 1995, the percentage of adopting farmers grew from 14% to 80%. In 1990, 7% of the total sorghum area (13 000 ha) was sown to the S 35 variety. By 1995, the area under S 35 had increased to 27% (66 000 ha). A yield advantage of about 51% over farmers' local varieties is associated with the adoption of S 35.

The three major constraints cited by farmers - susceptibility of the variety to bird attack, the high cost of seed, and low soil fertility - should assist in the formulation of future research priorities.

The research activities were supported by the United Nations Development Programme, the United States Agency for International Development, and donors supporting ICRISAT's unrestricted core activities.

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ICRISAT
International Crops Research Institute for the Semi-Arid Tropics
Patancheru 502 324, Andhra Pradesh, India
1999

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Contents

Background and introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is the most important cereal in the food system of Chad, and accounts for 70% of the total annual per capita cereal consumption (Table 1).

Sorghum is produced in Chad as a subsistence crop by a multitude of small-holders using family labor and traditional varieties as the main inputs. Consequently, average yields are low (below 600 kg ha^{-1}) and fluctuate greatly due to erratic rainfall conditions, creating chronic food deficits.

Research on the improvement of the productivity of basic food crops in Chad received national and international attention, especially after the severe droughts of 1973 and 1984, and the 1979-1982 civil war during which research infrastructures were disorganized, and stocks of improved and local seed varieties were largely lost (Ministere de la Recherche 1993, Kumar 1994). The overall strategy was to reconstruct the country's stock of genetic material and stabilize the seed production of improved varieties of sorghum and other basic crops. Research efforts were first aimed at extrapolating agricultural technologies from neighboring countries with agro-biociimatic conditions similar to those in Chad, and from regional and international research institutions such as the Semi-Arid Food Grain Research and Development (SAFGRAD), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and the International Institute for Tropical Agriculture (IITA). It was in this context that the S 35 sorghum variety from the Institut de la recherche agronomique (IRA) at Maroua, Cameroon, was introduced in Chad in 1986. A number of Food and Agriculture Organization of the United Nations/United Nations Development Programme (FAO/UNDP)-sponsored projects were created to support and stabilize the seed production of improved cultivars. Project CHD/82/003 entitled "Production de semences en zone sahelienne" and initiated in 1982 just after the civil war, could not start until 1985. It was followed by project CHD/87/002 entitled "Assistance a la production de semences en zone sahelienne" in 1987. The primary

Table 1. Average annual per capita cereal consumption (kg $capita^{-1}$ $year^{-1}$) in Chad, 1994-95.

Agroecological zone	Pearl millet	Sorghum	Maize	Rice
Sahelian Zone	60	60	30	0.7
Sudanian Zone	40	90	20	30
National average	50	70	20	10

Source: Ministere de l'Agriculture 1995.

objective of these projects, which were mainly focused on the more vulnerable Sahelian Zone, was to reinforce - technically and financially - local capacities in pure seed production and distribution. Research on food crops received substantial internal and external funding, and resulted in the development of important improved technologies, including the S 35 sorghum variety.

This study is a collaborative effort between ICRISAT and the Direction de la recherche et de la technologie agricoles (DRTA), the principal government agency responsible for agricultural research in Chad. The main objective was to evaluate the economic impact of the research and development (R&D) and diffusion of the S 35 sorghum technology in Chad. More specifically, the study pursued the following objectives

- determination of the performance and acceptability of S 35 technology in farmers' fields. This involved tracking the spread of the technology and collecting farmers' perceptions and perspectives in the semi-arid regions where the technology is applicable.
- evaluation of returns from research and diffusion investments on S 35
- discussion of other impact indicators related to food security, rural poverty, and sustainability
- setting of research priorities for sorghum improvement on the basis of the study's results.

This publication presents the impact analysis for sorghum S 35 in Chad, presenting details of district-level data, simulations, and analysis not included in an earlier paper in this series (Yapi et al. 1999), which emphasized on the germplasm research spillover concerning two countries in Central Africa, Cameroon and Chad.

Methodology

Previous reconnaissance surveys by ICRISAT and DRTA scientists had suggested the widespread adoption of S 35 sorghum in Chad (Baidu-Forson et al. 1995). In this study, survey methods were used to

- track the spread of the technology
- quantify the extent of its adoption
- collect the necessary information to assess its impact.

Survey methods - sampling

On-farm inquiries were carried out in 1995 through a formal survey using structured questionnaires.[1] The survey involved a sample *of* 152 farmers from 28 villages in four

1 The questionnaires were structured to collect annual farm-level information from 1990 (the year the technology was first released) to 1995. The period 1990-95 was therefore the survey years, and the adoption rates for these years are observed data.

subprefectures, all randomly selected from the three prefectures targeted by the release of S 35 in Chad. The sampling strategy followed four stages.

- The first stage involved the selection of three prefectures - Guera and Chari-Baguirmi (in the Sahelian Zone) and Mayo-Kebbi (in the Sudano-sahelian Zone) (Fig. 1), as they represented both the recommendation domain and the targeted zones for the release of the S 35 technology.
- The second stage involved the random selection of four subprefectures - one in each prefecture except for the Guera,where two subprefectures were selected.[2]
- The third stage involved the random and proportional selection of cantons (districts) and villages from each subprefecture - the number of villages and cantons selected was proportional to area and population size of the subprefectures.
- The fourth and final stage involved the random and proportional selection of farmers from villages - the selection of farmers was random, but the number of farmers selected in each village was proportional to the total number of farming units in the village. Approximately six farmers per village were selected.

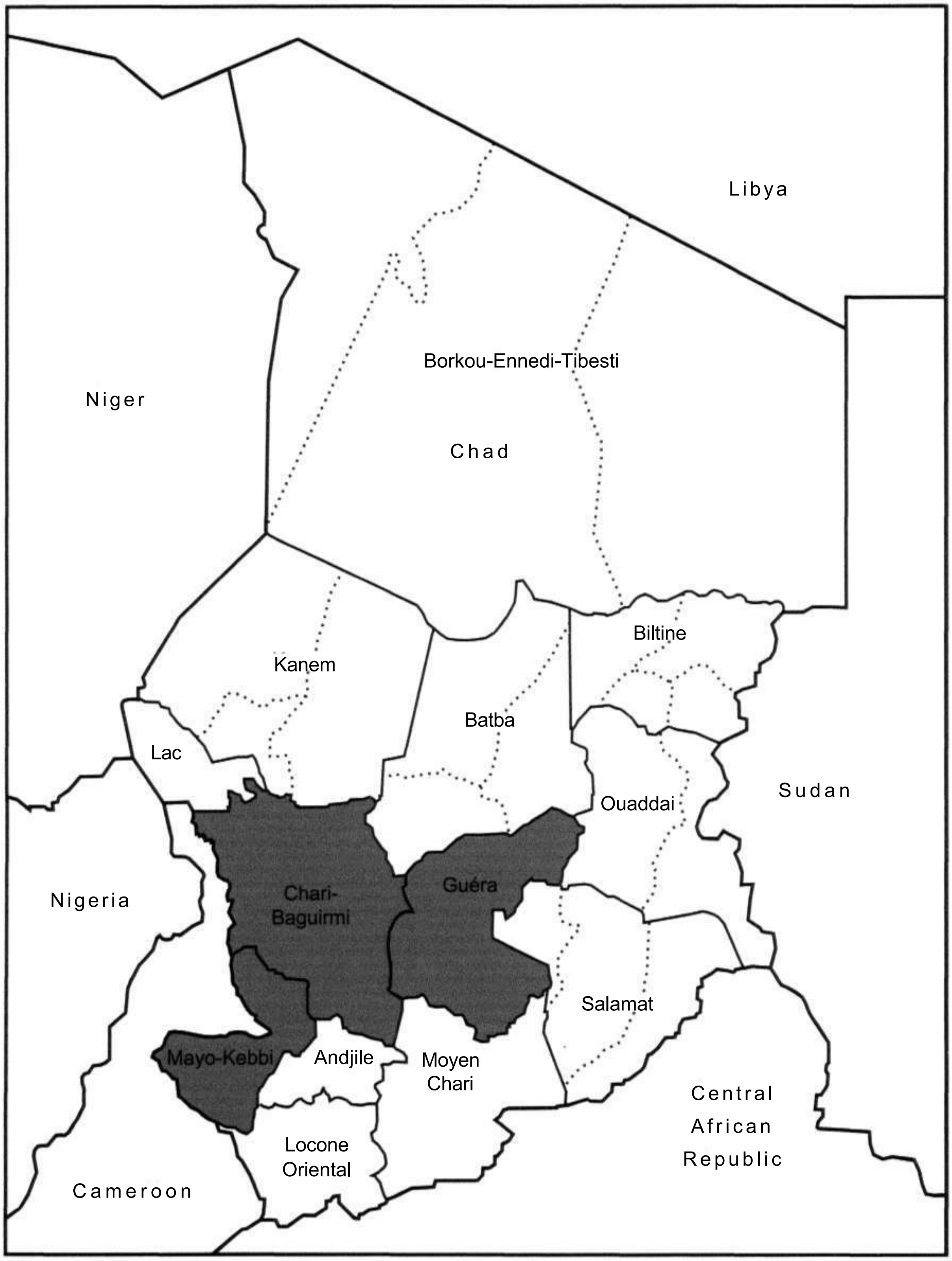
A survey questionnaire with multiple modules covering cropping systems, adoption patterns, farmers' perceptions and perspectives, farm cost structure, yield, and the utilization of seed, labor, and fertilizer inputs was used to collect the farm-level information that was required to evaluate the impact of the S 35 technology in the selected prefectures.

Analytical method

The analytical method used in this study to evaluate returns to S 35 research and diffusion investments is the economic surplus approach based on the well-known economic surplus principle. The foundation of this principle is the idea that the utilization of an improved technology has the potential to change the production-cost structure, increase market supply, and thus change market prices, resulting in welfare gains to producers and consumers (Bantilan 1996, Masters et al. 1995). Akino and Hayami (1975) presented an early and popular application of this approach. The welfare gain to producers, also referred to as producer surplus, is defined as the difference between the market price producers receive and the price at which they are willing to sell marginal units of their output up to the amount actually sold on

2. Two subprefectures were selected in the Guera in order to test an intial hypothesis about the effect of animal husbandry on the adoption of improved fertilizer-intensive varieties.Bitkine, a subprefecture with high animal husbandry activity, was included, in addition to Mongo, a randomly selected subprefecture with less animal husbandry activity. As the data did not show any difference in the patterns of adoption in the two subprefectures, the analysis for the Guera does not distinguish between them. The seasonal movement of livestock between regions of the prefectures may explain the lack of any significant difference in the adoption patterns.

Figure 1. Map of Chad showing the three study regions of Mayo-Kebbi, Chari-Baguirmi, and Guera.



the market. In terms of the demand-supply model, the area below the market equilibrium price line and above the supply curve represents producer surplus. Analogously, consumer surplus is defined as the difference between the price consumers actually pay and what they would have been willing to pay for each unit of the commodity up to the amount they actually purchase. Referring to the supply-demand apparatus, consumer surplus is measured by the area above the market price line and below the demand curve. The sum of the consumer surplus and the producer surplus is a measure of the economic surplus.

The adoption of improved technologies, which permits greater outputs per unit of available inputs, shifts marginal production cost structure down, thereby increasing producers' welfare. Consumers also stand to gain because greater quantities of the commodity are made available for consumption at a lower price.

Because international trade in sorghum is practically nonexistent in Chad, a simple, nontraded commodity model of the economic surplus approach was applied for impact evaluation. This simple framework is a single-period static model of a closed economy with a parallel shift in the supply function. It compares economic surpluses with and without S 35 research and diffusion.

Description of the study sites

The three prefectures -Guera Chari-Baguirmi, and Mayo-Kebbi - selected for this study fall largely in the targeted research zones of S 35. Together, these three regions produce on average 47% of the total output of annual rainfed sorghum in Chad, using 42% of the total harvested area of rainfed sorghum. The three regions are briefly characterized here in relation to their potential for the spread of the S 35 technology.

The prefecture of the Guera

The agroecology of the Guera is that of a typical Sahelian environment, characterized by sandy soils, sparse vegetation cover, and a mean annual rainfall that ranges between 400 and 700 mm. Long-term yield of rainfed sorghum in the prefecture averages 650 kg ha^{-1}, with significant variations between years of good rainfall, drought, or erratic rainfall conditions. For example, in 1990 (a year of poor rainfall conditions), the average sorghum yield stood at 500 kg ha^{-1} against 760 kg ha^{-1} in 1992, when rainfall conditions were normal (Ministere de I'Agriculture 1995). From 1988 to 1992, annual rainfall averaged 544 mm distributed over an average of 38 days between June and September. Terminal-drought situations have been frequent occurrences over the last two decades, causing repeated crop failures in systems dominated by farmers' traditional long-cycle sorghum varieties. Agricultural research did not target this region until after the 1984 drought and the severe famine that followed. S 35 is the very first improved sorghum variety to have been successfully released in the region.

The Guéra produces 10% of the country's total rainfed sorghum on approximately 10% of the country's total sorghum area. Small-holders using family labor and animal traction as the main inputs cultivate sorghum, the main cereal crop in the zone, as a subsistence crop (mostly as a sole crop). Animals are mainly used for plowing, organic fertilizer application, and harvested output hauling.

The prefecture of the Guéra is an area of low population density with about 5 inhabitants km^{-2}. Land is relatively abundant and low in value. Farmers in the region do not have easy access to input, output, and capital markets that are poorly developed. Agricultural systems are land-and labor-intensive. The Guéra is chiefly populated by six ethnic groups: the 'Arabs' (who represent 16% of the population), 'Kenga,' 'Dangaliat,' 'Moukoulou,' 'Dadjo,' and 'Djonkor.' The Arabs are exclusively herders who manage their livestock by transhumance. The other five ethnic groups are predominantly sedentary crop farmers who in addition raise some small and large farm animals. Farmyard manure (FYM) is the only source of fertilizer for sorghum farmers in the Guéra.

The prefecture of Chari-Baguirmi

The agroecology of the Chari-Baguirmi prefecture is of the Sudano-sahelian type, characterized by an average annual rainfall that ranges from 400 to 800 mm, sandy and clayey soils, and a vegetation cover slightly more abundant than that of the typical Sahelian environment. Long-term sorghum yields average 700 kg ha^{-1} but vary greatly with rainfall conditions. For example in 1990, a year of poor rainfall conditions (less than 500 mm annually), the average yield of rainfed sorghum was only 520 kg ha^{-1}, while in 1992, a year of normal annual rainfall (more than 550 mm), the average yield of rainfed sorghum reached 900 kg ha^{-1}. Chari-Baguirmi produces approximately 17% of the country's total annual output of rainfed sorghum on 15% of the total harvested area. Sorghum production is dominated by low-yielding, long-cycle traditional varieties that are well adapted to the region's environment and appreciated for their food quality. However, in the last two decades, it has generally been observed that the Sahelian and Sudano-sahelian Zones lose an isohyet every 10 years. S 35 cultivation is likely to increase if the trend continues.

Chari-Baguirmi is chiefly populated by four ethnic groups: the 'Baguirmi,' 'Kotoko,' 'Bornou,' and Arabs. Unlike the Arabs in the Guéra, the Arabs in Chari-Baguirmi are traders. The predominant occupation of the other ethnic groups is arable farming. With a total land area of 83 000 km^2 and a population density of about 15 inhabitants km^{-2}, Chari-Baguirmi is three times as densely populated as the Guéra.

The prefecture of Mayo-Kebbi

Mayo-Kebbi is the southernmost of the three prefectures. It is in the transitional area between the Sahelian and the Sudanian Zones, and has a higher average annual rainfall (600-1100 mm), less sandy soil, and a more abundant vegetation cover than the other two northern prefectures. Consequently, cereal-based crop production systems are more diversified in Mayo-Kebbi than in the other two regions. However, sorghum-based crop production systems are dominated by traditional varieties. Long-term yields of rainfed sorghum crops are also higher and average 780 kg ha^{-1}. Yield fluctuations are also important in this zone, for despite better rainfall conditions, sorghum continues to be grown as a subsistence crop in small, family-based farms ranging in size from 1 to 5 ha, using human labor and animal traction as the principal inputs. Cotton (Gossypium *hirsutum)* production was very important in the region and provided the bulk of farmers' revenue until 1985, when the cotton industry moved southward to the prefectures of Tandjilé, Logone Occidental, Logone Oriental, and Moyen-Chari. With a population density of 27 inhabitant km^{-2}, Mayo-Kebbi is not as land-abundant a zone as the Guera or Chari-Baguirmi. Farmers have limited access to both input and output markets, as the region is landlocked into the Cameroonian 'duck-beak.' It is inaccessible by road for most of the rainy season. Purchasable inputs, being difficult to locate and costly to transport, are expensive to use in the production of sorghum, a crop whose output market is poorly developed. FYM application remains a popular soil-fertility management practice among sorghum farmers in Mayo-Kebbi.

Estimation of S 35 R&D and diffusion costs in Chad

As mentioned earlier, R&D activities on S 35 started at ICRISAT-Patancheru and continued in Nigeria, Cameroon, and Chad. But for the purpose of this study, which seeks to quantify the impact of S 35 from the point of view of Chad, only expenditures incurred in Chad have been considered. S 35-related costs from elsewhere have been treated as 'sunk costs,' i.e., costs that would have been incurred even if S 35 had never reached Chad. Thus, the estimation of R&D costs took into consideration only S 35-related research and extension budgets at Gassi, ONDR, and NGOs represented by AICF. Budget records from 1985 to 1996 were looked up, and costs estimated on the basis of the salaries of research and diffusion team members and the time allocated to S 35-related activities. The process was tedious and could not have been completed without guidance from key senior staff members at the concerned institutions. The estimated costs are summarized in Table 2. The bases for their computation are detailed below.

Table 2. Annual costs[1] for S 35 R & D and diffusion in Chad.

Year of activity	Research costs at Gassi station	Cost of extension services		Total research and diffusion costs	
		ONDR[2]	AICF[3]	(CFA francs)	(US$)
1986	11528 040			11 528 040	46 112
1987	11528 040	0	0	11 528 040	46 112
1988	11528 040	0	0	11 528 040	46 112
1989	11528 040	13 143 000	6 661050	31 332 090	125 328
1990	11528 040	13 143 000	7 872 150	32 543 190	130 173
1991	11528 040	13 143 000	6 661050	31 332 090	125 328
1992	11528 040	13 143 000	4 844 400	29 515 440	118 062
1993	11528 040	13 143 000	0	24 671 040	98 684
1994	5 764 020	13 143 000	0	18 907 020	75 628
1995	5 764 020	13 143 000	0	18 907 020	75 628
1996	5 764 020	6 308 640	0	12 072 660	48 291

1. In CFA francs; CFA francs 250 = US$ 1.
2. Office national de development rural.
3. Action international contre la faim.

Table 3. Basis for the estimation of annual costs[1] for S 35 research at Gassi research station, Chad.

Research team members	Total annual costs	Proportion of time spent on R & D (%)	Budget allocation
1 principal breeder	15 000 000	50	7 500 000
2 local engineers	3 600 000	30	2 080 000
2 local technicians	2 160 000	40	864 000
6 field laborers	3 897 600	40	1 559 000
Operating expenses			525 000
Total			11528 040

1. In CFA francs; CFA francs 250 = US$ 1.

Estimation of S 35 research costs for Gassi

Table 3 provides the bases for the estimation of annual research costs at Gassi. Average costs shown are based on standard salary and benefits for typical officers in each category in Chad during 1986-1996.

After its release in 1989, S 35-related activities continued in the form of breeder seed production and the mass production of R_1 seed for distribution to farmers, extension services, and NGOs until 1993, the year of the departure of the FAO/

Table 4. Annual cost[1] items of a typical Office national de development rural (ONDR) agent in Chad.

Budget items	Total budget	S 35 portion of budget	Budget allocation
1. Salary	960 000	1/3	320 000
2. Benefits	175 000	1/3	58 333
3. Motorcycle purchase	100 000	1/3	33 333
4. Motorcycle repairs and fuel	220 000	1/3	73 334
5. Supplies	20 000	1/3	6 667
6. On-farm trials	51000	1/3	17 000
7. Other expenses	51 160	1/3	17 053
Total	1 577 160	1/3	525 720

1. In CFA francs; CFA francs 250 = US$ 1.

UNDP-sponsored breeder (personal communication with Dr Simon Assegninou, FAO/UNDP-sponsored breeder at Gassi, 1996). From 1986 to 1993, the research team with a total annual budget allocation of CFA francs 11.5 million (about US$ 46 000; CFA francs 250 = US$ 1) remained unchanged. From 1994 to 1996, the remaining research team members continued to support the transfer of S 35 technology through the production and distribution of pure seed in the form of mini-doses at 50% of the expenditure of previous years (i.e., CFA francs 5 764 020 or US$ 23 000).

Estimation of S 35 diffusion costs for ONDR

On the basis of the information received from ONDR agents and administrators in N'djamena, Bongor, and Bitkine, the annual cost items for a typical ONDR extension agent were identified and budgeted at CFA francs 1 577 160 (Table 4).

It was estimated that one-third of the time of a typical ONDR agent from 1989 to 1995 was spent on S 35-related extension activities. This represents an annual budget allocation of CFA francs 525 720 per agent (Table 4, column 4). The average cost per agent was then multiplied by 25 (the average number of ONDR agents in the Guera, Mayo-Kebbi, and Chari-Baguirmi from 1989 to 1995) to obtain the total annual costs (approximately CFA francs 13 million or US$ 52 000) of ONDR's extension activities during the period. ONDR has estimated that by 1996, only half (i.e., 12) of its agents' services would be needed for S 35 extension activities (mainly seed distribution and sowing dates trials). This represents an annual cost of approximately CFA francs 6 million (about US$ 24 000) for 1996 and beyond.

Estimation of S 35 diffusion costs for AICF

AICF's intervention in rural Chad consists of introducing farmers in drought-prone, food-deficient areas to improved technologies, A team of extension agents conducts its activities, which includes agricultural engineers, field technicians, and cooperating farmers. In the case of the S 35 technology, AICF's extension activities covered the period from 1989 to 1992, with an estimated annual cost per agent of CFA francs 605 550 (about US$ 2420). AICFs annual costs for S 35 diffusion between 1989 and 1992 were estimated (Table 5) by taking into account the total number of agents per year.

Results and discussion

Patterns of adoption

Results of the adoption surveys confirmed that within six years of its release, S 35 had spread quite significantly in the zones targeted by research and extension activities, especially in the drought-prone Guera (Table 6, column 2). Adoption rates are defined as percentages of the total rainfed sorghum area sown to S 35 in each region. The aggregated rates (Table 6, column 5) are weighted averages of the regional rates.

Table 5. Estimated costs[1] of S 35 diffusion incurred by Action internationale contre la faim (AICF) in Chad, 1989-1992.

Year of activity	Number of agents	Average agent cost	Total extension costs
1989	11	605 550	6 661 050
1990	13	605 550	7 872 150
1991	11	605 550	6 661 050
1992	8	605 550	4 844 400

1. In CFA francs; CFA francs 250 = US$ 1.

Table 6. Adoption of S 35 (as % of total rainfed sorghum area) in the Guéra, Mayo-Kebbi, and Chari-Baguirmi, Chad, 1990-95.

Year	Guéra	Mayo-Kebbi	Chari-Baguirmi	All three regions
1990	17(14)[1]	7(14)	0(0)	7
1991	22 (23)	8(15)	0(0)	8
1992	23(41)	1.0 (28)	14 (40)	14
1993	28(58)	17 (47)	21 (80)	20
1994	32(84)	22 (72)	22 (60)	24
1995	38(84)	27 (75)	24 (80)	27

1 .Numbers in parentheses are percentages of farmers who adopted the technology.

The adoption rates presented in Table 6 are quite variable between regions. They are higher and increase more rapidly in the totally Sahelian Guera than in the Sudano-sahelian Mayo-Kebbi and Chari-Baguirmi. Apart from ecological differences, the differential rates of adoption in the three regions can, perhaps, be better explained by the quantity of pure seed made available to farmers in each region. As the primary release target zone,Guera benefited, not only from most of the S 35 extension services provided by ONDR and NGOs, but also from the large-scale pure seed production campaign that was initiated two years before the variety was formally released.

Adoption of S 35 in Mayo-Kebbi started slowly. In 1990, the adoption rate was only 7% but by 1995 it had increased to 27%. This is quite spectacular for a region where seed distribution is severely limited by poor road infrastructure, and where consumer preferences favor red- as opposed to white-grained sorghum varieties such as S 35. This is, perhaps, an indication that food preferences could change with changing physical environments.[3]

Adoption of S 35 in Chari-Baguirmi did not begin until two years after its release. The initial rate of adoption was rather high (14% in 1992). Three years later (i.e., 1995), the rate of adoption had increased to 24%. This is also quite impressive for a region where preliminary on-farm test results had discouraged intensive extension activities by ONDR. These results are the fruits of individual activities by isolated NGOs [(e.g., Secours catholique pour le development (SECADEV), Cooperation for American Relief Everywhere (CARE), and Voisins Mondiaux].

Table 7. Estimated area (ha) of S 35 sorghum production in the three study regions in Chad, 1990-95.[1]

Year	Guera		Mayo-Kebbi		Chari-Baguirmi	
	Total area	S 35 area	Total area	S 35 area	Total area	S 35 area
1990	46 100	7 837	73 900	5 173	50 500	0
1991	48 000	10 560	81 000	6 480	79 000	0
1992	43 400	9 982	83 500	8 350	107 700	15 078
1993	32 700	9 156	89 300	15 181	62 300	13 083
1994	49 000	15 680	93 074	20 476	91 913	20 221
1995	40 990	15 576	98 149	26 500	98 120	23 549

1. S 35 areas were obtained by multiplying the total rainfed sorghum area of each year by the corresponding adoption rate.

Source: Ministere de l'Agriculture 1995.

3. According to Dr Simon Assegninou [former senior scientist (breeding) at the Centre semencier de Gassi], when S 35 was first released, a senior officer at the Ministry of Agriculture made the remark that S 35 was not for Mayo-Kebbi farmers. People in the Mayo-Kebbi region traditionally have strong preference for red-grained as opposed to white-grained sorghum varieities. Past efforts to introduce white-grained sorghum varieties (berbere, for example) have been unsuccessful in the region.

Table 8. Effects of management practices on yields of S 35 and local sorghum varieties in Chad.

Management practices	Yield of S 35 (kg ha^{-1})	Yield of local varieties (kg ha^{-1})
Technological package 1	1605[1]	1516[1]
Sowing period: 15 Jun-15 Jul		
Sowing density: 62-500 plants ha^{-1} (80 cm X 40 cm X 2 plants)		
Resowing 7 days after sowing		
Weeding, thinning, and bird scaring		
Technological package 2		
Technology package 1 + urea application (100 kg ha^{-1})	1866[1]	1721[1]
Technology package 1 + urea application (100 kg ha^{-1})	1333[2]	719[2]

1. These yields are averages of 42 multilocational tests conducted in 1985, a year of good rainfall conditions (729 mm).
2. These yields are averages of 88 multilocational tests conducted in 1984, a year of poor rainfall conditions (529 mm).

Source: Johnson et al, 1986.

The patterns of adoption and the corresponding areas sown to S 35 (Table 7) clearly indicate that farmers in the drought-prone regions of Chad have started replacing their long-cycle landraces with the short-duration S 35 sorghum variety.

Farmers' perceptions

Why are farmers eager to adopt the S 35 technology? Why are they willing to change their management practices for the S 35 sorghum variety but not for local varieties? The on-farm surveys provide a two-fold answer to these questions.

Firstly, farmers prefer S 35 over traditional varieties because the new technology is early-maturing, high-yielding, and has good food and fodder characteristics. The short-duration trait of S 35 is an obvious advantage in drought-prone areas where

Box 1 S 35 sorghum as a food security crop

"We always keep S 35 seed around the house as a security," said a group of farmers in the village of Niergui (Guera)."When rains do not come on time or when they stop too soon, our own varieties give us nothing, so we sow this one," said farmer Toralet, as he proudly held up a few good-looking panicles of S 35. "This is the sorghum that never fails; rains or no rain it always gives you something. Its 'botde' and couscous are good too! I have now been cultivating it every year since 1991," he added.

farmers' long-cycle local varieties frequently fail due to delayed or inadequate rainfall Indeed, the area sown to S 35 varies from year to year depending on farmers' perceptions of the probable length of the growing season, either at the onset of rains or after a mid-season drought. They sow more of the S 35 variety when the rainy season is perceived to be bad. (See Box 1 for related farmers' comments.)

The Guera, and the southern regions of Chari-Baguirmi and Mayo-Kebbi, are now highly drought-prone, having dried out considerably over the last two decades. Farmers' traditional long-cycle guinea sorghum varieties have as a result become very vulnerable to terminal drought. This has encouraged farmers to consider including short-duration varieties such as S 35, which are drought-resistant, high yielding, and possess good food characteristics, in their production systems.

Secondly, farmers are willing to change their management practices for the S 35 sorghum variety because the required management practices are simple, familiar, and are not capital intensive (Table 8). These changes can be easily implemented with locally available family labor and animal traction inputs (Table 8, Technological package 1). Furthermore, the benefits from implementing these changes are substantial, and include food security, high productivity of inputs, and reductions in the per unit production cost. As shown in Table 8, the required changes for "Technological package 1" are minimal, as no additional capital investment is necessary. Yet, the practices recommended in the package provide significant benefits (1605 kg ha^{-1} against 1516 kg ha^{-1} for the local varieties) in years of good rainfall conditions. In years of poor rainfall, the yield advantage is manifold (Table 9, column 2). If, in addition, urea is used at a rate of 100 kg ha^{-1} (Table 8, Technological package 2), the yield of S 35 can be increased to 1866 kg ha^{-1}, giving a fertilizer effect of 261 kg ha^{-1} (16%) against 1721 kg ha^{-1} for local varieties.

Farmers in Chad practice plowing and line sowing in addition to the minimum management requirements mentioned in Table 8. Farmers have reported that normal plowing with animal traction not only improves crop yields, but also prevents heavy weed infestations. This facilitates weeding tasks, especially the first weeding. Scientists at IRA-Maroua, Cameroon, tested the effect of plowing on S 35 yield and found it to be minimal. But they stated that under adverse rainfall conditions, plowing might be more important. They recognized that plowing facilitates field weeding, which is known to improve productivity.

Constraints to the adoption of the S 35 technology

Adoption of the S 35 technology has not been entirely free of constraints. But of the three major problems associated with the technology, only one is related to the variety

Table 9. Grain yield (kg ha^{-1}) of sorghum varieties in on-farm tests in northern Cameroon, 1984-87.

Year	1984	1985	1986	1987	1984-87
Rainfall[1] (mm)	529	729	773	614	-
Yield of S 35	1333	1689	1866	1888	1694
Yield of local varieties	717	1539	1721	1825	1451[2]
Yield of other introduced varieties[3]	784	1202	2185	1974	1536[4]
Number of sites	88	79	38	35	240
Yield difference: S 35 over local varieties (%)	85	9.7	8.4	3.5	26.7

1. Mean total across selected sites.
2. Mean yield of Dueling, a local variety. The mean yield of local Djigari varieties in 1988 was 1336 kg ha^{-1}.
3. Mean yields of E 35-1 and E 38-3 in 1984; S 34, S 36, S 20, and 82 S 50 in 1985; CS 54 and CS 61 in 1986 and 1987.
4. Mean yields of CS 54.

Source; Kamuanga and Fohasso 1994.

itself The other two have to do with farmers' socioeconomic conditions and the physical environments of their fields.

Farmers reported the susceptibility of S 35 to bird attack as the variety's single most important problem. This problem is attributed to both the early-maturity characteristic and the sweet grain of the variety. If sown too early, together with farmers' long-cycle traditional varieties, S 35 matures first, standing thus as the sole grain available. The problem should be reduced as more farmers adopt the variety and are made aware of the appropriate sowing dates for S 35 in each region. This constraint has been cited by a larger percentage of farmers in Mayo-Kebbi (100%) than in Chari-Baguirmi (62%) and the Guera (24%). This indicates the degree to which the 'date-of-sowing' was stressed in extension activities in the three regions. Indeed, only in the Guera were sowing dates experiments conducted during diffusion of the S 35 variety.

A second major constraint to the adoption of the S 35 technology is the declining soil fertility of farmers' fields. This problem is more serious in the Guera (where arable land area is limited by the predominance of enormous mountain chains) and Chari-Baguirmi (where rural population density is relatively high) than in Mayo-Kebbi (where 50% of the population lives in urban areas). Growing population, soil erosion, and overgrazing have contributed to the soil-degradation problem in these regions.

The third constraint to S 35 adoption cited by farmers is seed shortage (i.e., seed unavailability when required, in the appropriate quantities, and at affordable prices). The mini-dose approach used by the Gassi seed project has been useful in supplying many farmers with pure seed. Because the mini-doses are in small quantities, they can be easily transported to remote areas that are inaccessible by road. This is an obvious advantage of the mini-dose system, but, unfortunately, the quantity affordable (one or two packages of 250 g) is not sufficient to allow farmers to go directly into production. Farmers are expected to purchase a small quantity of pure seed in the form of mini-doses, from which they must produce their own seed for cropping in the next season. (See Box 2 for an illustrative comment)

Box 2 Problem with the mini-dose approach

"I tried the mini-dose approach twice before I was able to produce enough seed on my own," said Danhla, a farmer from the village of Guissede in Mayo-Kebhi. "I wish I were able to buy enough pure seed for direct sowing in my 2 -ha field," he added.

Indeed, 20 kg of seed (that is 80 packages of 250 g of mini-doses) are required to sow 2 ha. At a 1994 unit cost of CFA francs 150 (see Table 10), farmer Danhla would have spent CFA francs 12 000 on seed alone in order to cultivate 2 ha of S 35. This is clearly a prohibitive amount of money for most farmers.

Researchers at Gassi recognize this shortcoming of the mini-dose approach but attribute the problem to the highly unpredictable nature of the demand for S 35 seed. They, along with ONDR extension agents, argue that the demand for S 35 seed is highly elastic and depends on what farmers perceive the season to be like. (See Box 3 for a comment by an officer of the ONDR.)

Box 3 The difficulty in adequately planning the supply of pure seed of S 35

It is usually when no significant rainfall occurs by 15 June that farmers become most nervous and rush for S 35 seed," said Mr Cross Pierre Founsoumna, Chief of the Guelengdeng.ONDR office. "In normal years, farmers tend to demand less of the variety from us as their demands are adequately met with the traditional farmer-to-farmer seed exchanges. It is very hard for us to predict future rainfall conditions and produce S 35 seed accordingly," he concluded.

Economic benefits from S 35 adoption

This section presents the quantitative indicators of the impact of S 35 adoption in Chad. The premises for evaluating the benefits are set first.

Premises of the benefits evaluation. The assessment of returns to S 35 research and diffusion investments and the determination of farm-level impacts were computed

Table 10. Prices of S 35 packaged in mini-doses for sale to extension services and farmers in Chad, 1990 and 1994.[1,2]

Mini-dose packages	Sale prices for ONDR and NGOs		Sale prices for farmers	
	1990	1994	1990	1994
Wholesale price (kg^{-1})	160	240	-	-
Packages of 5 kg	700	1050	800	1200
Packages of 1 kg	160	255	180	300
Packages of 250 g	80	120	100	150

1. In CFA francs; CFA francs 250 = US $ 1.
2. Extension services include NGOs and the Office national de developpement (ONDR).
Source: Saleh et al. 1994.

using secondary data obtained from national agricultural statistics of base price and production levels (Table 11). The base levels of price and production are averages over the period 1986-88.

Farm cost structure. The cost structure of producing S 35 is compared to that of the best local varieties available to farmers in each region (Tables 12, 13, 14, and 15). This is done on the basis of the survey data. The additional costs of production are mainly to be found under the heads 'land/soil preparation,' 'hauling of output,' and 'bird scaring.' Land preparation for S 35 cultivation entails additional costs because it requires plowing and row ridging according to extension recommendations. Animal traction is used for these activities. The hauling of the output of S 35 requires additional costs because it is high yielding. It is interesting to note from the cost-structure tables that although S 35 yields approximately 50% more than farmer's local varieties, its harvest does not require any additional labor. The adoption of the S 35 technology has also increased the productivity of farm labor. Farmers say that the efficiency of labor is explained by

- the softness of the S 35 stalk and the medium height of its plant (about 200 cm against 440 cm for farmers' varieties), which allow for easy harvesting. Farmers are able to reach in and cut the S 35 panicle directly without having to knock down the stalk first and then cut the panicle, as is the case while harvesting traditional varieties
- the line-sowing of S 35, which facilitates movements across the field during harvest.

However, the susceptibility of the S 35 technology to bird damage has made bird scaring a necessary crop-protection activity, adding to the costs of producing the variety.

Table 11. Background information on sorghum area, production, and price[1] in the three study regions in Chad, 1984–1994.

Year	Guéra			Mayo-Kebbi			Chari-Baguirmi			All three regions		
	Area (ha)	Output (t)	Price (CFA francs kg^{-1})	Area (ha)	Output (t)	Price (CFA francs kg^{-1})	Area (ha)	Output (t)	Price (CFA francs kg^{-1})	Area (ha)	Output (t)	Price (CFA francs kg^{-1})
1984	47 584	32 138	110.49	32 419	20 466	120.10	8 850	5 225	115.30	88 853	57 829	115.30
1985	47 155	31 688	112.42	38 770	26 142	122.20	9 860	6 982	117.31	95 785	64 812	117.31
1986	46 727	31 238	43.52	45 120	31 818	47.30	19 339	11 295	45.41	111 186	74 351	45.41
1987	46 298	30 788	27.97	51 471	37 494	30.40	28 818	15 395	29.18	126 587	83 677	29.18
1988	35 910	25 137	65.04	54 940	54 720	70.70	40 661	30 089	67.87	131 511	109 946	67.87
1989	56 983	39 880	57.13	62 394	43 301	62.10	35 070	16 057	59 62	154 447	99 238	59.62
1990	46 100	23 050	52.26	73 900	50 400	56.80	50 500	26 260	54.53	170 500	99 710	54.53
1991	48 000	32 200	74.34	81 000	57 750	80.80	79 000	61 540	77.57	208 000	151 490	77.57
1992	43 400	33 000	44.60	83 500	63 043	68.40	107 700	96 800	52.40	234 600	192 843	52.40
1993	32 700	16 330	34.80	89 300	59 473	42.80	62 300	31 075	38.50	184 300	106 878	38.50
1994	49 000	33 320	110.30	93 074	92 701	96.80	91 913	71 874	109.30	233 987	197 895	109.30

1.CFA francs 250 = US$ 1.
Source: Ministère du plan et de la coopération 1993.

Table 12. Cost analysis of S 35 research and diffusion impact for all three regions (Guera, Mayo-Kebbi, and Chari-Baguirmi, Chad) together.

Production cost items	Unit	Local variety			S 35 variety		
		Unit price (CFA francs)	Total input	Total cost (CFA francs)	Unit price (CFA francs)	Total input	Total cost (CFA francs)
Variable costs ha^{-1} $year^{-1}$							
Labor costs							
Land/soil preparation	days	500	9.67	4833	500	11.33	5667
Sowing	days	500	10.00	5000	500	10.00	5000
Resowing	days	500	0.33	167	500	0.33	167
Manure application	days	500	1.17	583	500	1.17	583
Weeding							
No 1	days	500	39.33	19 667	500	35.00	17 500
No 2	days	500	25.00	12 500	500	21.00	10 500
No 3	days	500	1.00	500	500	1.00	500
Plant protection[1]							
No 1	days	500	0	0	500	0	0
No 2	days	500	0	0	500	0	0
No 3	days	500	0	0	500	0	0
Bird scaring	days	500	2.20	1100	500	14.33	7167
Harvesting	days	500	12.00	6000	500	12.00	6000
Threshing/winnowing	days	500	6.83	3417	500	7.50	3750
Hauling	days	500	3.17	1583	500	4.00	2000
Storage	days	500	1.50	750	500	1.33	667
Seed	kg	85	9.67	822	370	10.00	3700
Insecticide (seed dressing)	kg	750	0	0	750	0	0
Equipment/animal traction	days	1125	2.00	2250	1125	4.00	4500
Farmyard manure	cartloads						2240
	(25-30 kg)	280	8.00	2240	280	8.00	2240
Commercial fertilizer	kg	475	0	0	475	0	0
Total variable costs				61 412			69 940
Fixed costs							
(imputed value of land)	CFA francs[2]	5000	1.00	5000	5000	100	5000
Total costs				66 412			75 940
Output ha^{-1} $year^{-1}$	t			0.760			1.15
Change in output	%						51
Total value of output	CFA francs r^{-1}	85 000		64 600	120 000		138 000
Unit cost assessment							
Unit total cost	CFA francs r^{-1}			87 384			66 035
Unit variable cost	CFA francs r^{-1}			80 805			60 817
Unit variable cost reduction	CFA francs r^{-1}						19 987

1. Includes spraying.
2. CFA francs 250 = US$1.

Table 13. Cost analysis of S 35 research and diffusion impact for theGuera, Chad.

Production cost items	Unit	Local variety			S 35 variety		
		Unit price (CFA francs)	Total input	Total cost (CFA francs)	Unit price (CFA francs)	Total input	Total cost (CFA francs)
Variable costs ha^{-1} $year^{-1}$							
Labor costs							
Land/soil preparation	days	500	4	2000	500	6	3000
Sowing	days	500	8	4000	500	8	4000
Resowing	days	500	1	500	500	1	500
Manure application	days	500	1	500	500	1	500
Weeding							
No 1	days	500	46	23 000	500	41	20 500
No 2	days	500	34	17 000	500	31	15 500
No 3	days	500	3	1500	500	2	1000
Plant protection[1]							
No 1	days	500	0	0	500	0	0
No 2	days	500	0	0	500	0	0
No 3	days	500	0	0	500	0	0
Bird scaring	days	500	1	500	500	13	6500
Harvesting	days	500	10	5000	500	10	5000
Threshing/winnowing	days	500	3.5	1750	500	2	1750
Hauling	days	500	2	1000	500	2	1500
Storage	days	500	1.5	750	500	2	1000
Seed	kg	85	10	850	370	10	3700
Insecticide (seed dressing)	kg	950	0	0	950	0	0
Equipment/animal traction	days	1125	2	2250	1125	4	4500
Farmyard manure	cartloads (25-30 kg)	280	10	2800	280	10	2800
Commercial fertilizer	kg	675	0	0	675	0	0
Total variable costs				63 400			71 750
Fixed costs (imputed value of land)	CFA francs[2]	5000	1	5000	5000	1	5000
Total costs				68 400			76 750
Output ha^{-1} $year^{-1}$	t			0.710			1.09
Change in output	%						54
Total value of output	CFA francs t^{-1}	85 000		60 350	120 000		138000
Unit cost assessment							
Unit total cost	CFA francs t^{-1}			96 338			70 413
Unit variable cost	CFA francs t^{-1}			89 296			65 825
Unit variable cost reduction	CFA francs t^{-1}						23 471

1. Includes spraying.
2. CFA francs 250 = US$1.

Table 14. Cost analysis of S 35 research and diffusion impact for Mayo-Kebbi, Chad.

Production cost items	Unit	Local variety			S 35 variety		
		Unit price (CFA francs)	Total input	Total cost (CFA francs)	Unit price (CFA francs)	Total input	Total cost (CFA francs)
Variable costs ha^{-1} year^{-1}							
Labor costs							
Land/soil preparation	days	250	15	3750	250	16	4000
Sowing	days	250	11	2750	250	11	2750
Resowing	days	250	0	0	250	0	0
Manure application	days	250	0.5	125	250	0.5	125
Weeding							
No 1	days	250	31	7750	250	26	6500
No 2	days	250	23	5750	250	16	5750
No 3	days	250	0	0	250	1	250
Plant protection[1]							
No 1	days	250	0	0	250	0	0
No 2	days	250	0	0	250	0	0
No 3	days	250	0	0	250	0	0
Bird scaring	days	250	4	1000	250	28	7000
Harvesting	days	250	19	4750	250	19	4750
Threshing/winnowing	days	250	12	3000	250	14	3500
Hauling	days	250	5	1250	250	6	1500
Storage	days	250	2	500	250	1	250
Seed	kg	80	9	720	370	10	3700
Insecticide (seed dressing)	kg	950	0	0	950	0	0
Equipment/animal traction	days	1125	2	2250	1125	4	4500
Farmyard manure	cartloads (25-30 kg)	380	6	2280	380	6	2280
Commercial fertilizer	kg	675	0	0	675	0	0
Total variable costs				35 875			45 150
Fixed costs (imputed value of land)	CFA francs[2]	5000	1	5000	5000	1	5000
Total costs				40 875			50 105
Output ha^{-1} year^{1}	t			0.78			1.19
Change in output	%						53
Total value of output	CFA francs t^{-1}	85 000		66 350	120 000		142 800
Unit cost assessment							
Unit total cost	CFA francs t^{-1}			52 404			42 105
Unit variable cost	CFA francs t^{-1}			45 994			37 903
Unit variable cost reduction	CFA francs t^{-1}						8 091

1. Includes spraying.
2. CFA francs 250 = US$1.

Table 15. Cost analysis of S 35 research and diffusion impact for Chari-Baguirmi, Chad.

Production cost items	Unit	Local variety			S 35 variety		
		Unit price (CFA francs)	Total input	Total cost (CFA francs)	Unit price (CFA francs)	Total input	Total cost (CFA francs)
Variable costs ha^{-1} year^{-1}							
Labor costs							
Land/soil preparation	days	500	10	5000	500	12	6000
Sowing	days	500	11	5500	500	11	5500
Resowing	days	500	0	0	500	0	0
Manure application	days	500	2	1000	500	2	1000
Weeding							
No 1	days	500	41	20 500	500	38	19 000
No 2	days	500	18	9000	500	16	1000
No 3	days	500	0	0	500	0	0
Plant protection[1]							
No 1	days	500	0	0	500	0	0
No 2	days	500	0	0	500	0	0
No 3	days	500	0	0	500	0	0
Bird scaring	days	500	1.6	800	500	2	1000
Harvesting	days	500	7	3500	500	7	3500
Threshing/winnowing	days	500	5	2500	500	5	1750
Hauling	days	500	2.5	1250	500	3	1500
Storage	days	500	1	500	500	1	1000
Seed	kg	85	10	0	370	10	3700
Insecticide (seed dressing)	kg	950	0	0	950	0	0
Equipment/animal traction	days	1125	2	2250	1125	4	4500
Farmyard manure	cartloads (25-30 kg)	280	8	2240	280	8	2240
Commercial fertilizer	kg	375	0	0	375	0	0
Total variable costs				54 890			58 940
Fixed costs							
(imputed value of land)	CFA francs[2]	5000	1	5000	5000	1	5000
Total costs				59 890			63 940
Output ha^{-1} year^{-1}	t			0.81			1.18
Change in output	%						46
Total value of output	CFA francs t^{-1}	85 000		68 850	120 000		141600
Unit cost assessment							
Unit total cost	CFA francs t^{-1}			73 938			54186
Unit variable cost	CFA francs t^{-1}			67 765			49 949
Unit variable cost reduction	CFA francs t^{-1}						17 816

1. Includes spraying.
2. CFA francs 250 = US$1.

Projection of S 35 adoption rates. The adoption rates of the S 35 technology derived from the survey data have been projected backwards and forwards beyond the survey years (1990-95) using the logistic function.[4] Ceiling rates of 60% for the Guera, 40% for both Mayo-Kebbi and Chari-Baguirmi, and 50% for the three regions as a whole were set in the projection process. Relatively low ceiling rates were set because it was felt that the removal of constraints to S 35 adoption (especially land/soil fertility and pure seed availability) would require major political initiatives, which are unlikely to be realized in the foreseeable future. Therefore, low ceiling rates were set on the basis of current levels of extension, seed production and distribution efforts by Gassi, and other governmental and nongovernmental rural development organizations operating in the different regions.

Demand and supply elasticities. Estimates of demand and supply elasticities are important factors in the economic surplus analytical framework. Because such parameter estimates for sorghum were not available from previous studies in the western and Central Africa region, and given that elasticities are highly unstable through time and over economic environments, values (0.50 and - 0.30, respectively, for supply and demand elasticities) were assumed and tested subsequently through sensitivity analyses.

The rational for setting the demand elasticity is based on the definition of demand elasticity itself:

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

where,

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

In Chad, as in most developing countries where coarse cereals (e.g., sorghum and pearl millet) are considered to be 'poor man's crops,' demand is characterized by low levels of substitution (i.e., $-1 < \sigma < 0$), high budget share (i.e., $0.10 < p < 0.50$), and high sensitivity to income levels (i.e., $0.20 < \mu < 0.80$). Therefore, parameter values

4. The functional form of the logistic function used is: $$A_t = \frac{C}{1 + e^{-(a+bt)}}$$

Where A_t is the adoption rate at time t; C is the maximum adoption rate; *a* and *b* are parameters. C was based on the projections and a and *b* were estimated using the observed adoption rates for the survey years (1990-95). The year to year changes in the adoption of the technology were reflected in the backward and forward projections, these changes being embedded in the observed adoption rates. For example, using the aggregate observed adoption rates (1990-95 rates) and value of 50% for the ceiling rate, values of-2.21 were estimate for *a* and 0.40 for *b*.

of -0.1 (for σ), 0.4 (for p), and 0.5 (for (μ) were set in the benefits evaluation process, yielding an elasticity of demand of -0.30.

The assumed value for the supply elasticity (0.5) is based on the fact that sorghum in Chad remains a subsistence crop, produced primarily for home consumption and not for the market. Furthermore, current production constraints are such that supply response to output price change is unlikely to be significant, at least in the short term.

Indicators of profitability. On the basis of the premises set above, the net present value (NPV) of benefits from the adoption of S 35 is estimated at US$ 15 million (or 7.5 billion CFA francs) for the three regions as a whole at a discount rate of 10%. This represents an internal rate of return (IRR) of 95% (Table 16). Subsequent sensitivity analyses showed that the NPV and IRR do not vary with alternative parameter values (Tables 17a, 17b, and 17c). Regional benefits analyses were also conducted that showed higher benefits for the Guera region (where rates of adoption were higher) than for the other two regions (where rates of adoption were lower). Distributions of gains were in favor of consumers (62.5% as opposed to 37.5% for producers).

Food-security indicator. The adoption of the S 35 technology (variety and recommended practices) has allowed farmers to produce more output ha"[1] with minimum additional costs. The estimated yield advantage of S 35 over the best of farmers' traditional technologies was substantial, and ranged from 46% in Chari-Baguirmi to 53% in both Mayo-Kebbi and the Guera (Table 18).

With such an increase in productivity, farmers are in a better position to feed their families, make provisions for famine years, and secure surpluses (albeit small) for the market. Farmers reported that with S 35 they do not need to extend their fields over large areas to be able to feed their families. (See Box 4 for illustrative comments from farmers.)

Box 4 S 35 as a food sufficiency and land saving crop

"I used to sow 2 ha of my own variety of sorghum each year in order to feed my family," said farmer Issaka from the village of Niergui,Guera,"I now sow only 1 ha with S 35. I grow vegetages on half of the other hectare," he added. For Bouda, a farmer from the village of Tchigali II in Mayo-Kebbi, the short duration trait of the S 35 variety is a real advantage, not just because it helps escape terminal drought, hut also matures much earlier, thereby reducing the hunger period before the next harvest. "Ever since I first tried the S 35 variety in 1992, I sow half a hectare of it each year. This way I can feed my family even as I wait for the sorghum of our ancestors to mature," he said.

Table 16. Evaluation of benefits from S 35 research and diffusion: aggregate analyses for the three study regions in Chad.[1]

Year	Net benefits (US$)	Total (US$)	Estimated research costs			Estimated research gains (US$)			Distribution of benefits			
			Gassi[2,3] (CFA francs)	ONDR[4] (CFA francs)	AICF[5] (CFA francs)	Total	Adoption level	Annual gains	Gains to consumers (CFA francs)	Gains to consumers (%)	Gains to producers (CFA francs)	Gains to producers (%)
Net present value	15 093 740	685 088	85 909 021	92 743 537	20 874 745	23 101 782		73 359 649	14 438 614		8 663 168	
Total value	91 721 671	1 997 853	236 324 820	237 099 720	26 038 650	93 719 523		227 056 489	89 402 351		35 144 821	
1986	-46 112	46 112	11 528 040	0	0	0	0	0	0	0	0	0
1987	-46 112	46 112	11 528 040	0	0	0	0	0	0	0	0	0
1988	-46 112	46 112	11 528 040	0	0	0	0	0	0	0	0	0
1989	-125 328	125 328	11 528 040	13 143 000	6 661 050	0	0	0	0	0	0	0
1990	417 895	130 173	11 528 040	13 143 000	7 872 150	548 067	0.07	7 829 534	342 542	62.5	205 525	37.5
1991	501 034	125 328	11 528 040	13 143 000	6 661 050	626 363	0.08	7 829 534	391 477	62.5	234 886	37.5
1992	978 073	118 062	11 528 040	13 143 000	4 844 400	1 096 135	0.14	7 829 534	685 084	62.5	411 051	37.5
1993	1 467 223	98 684	11 528 040	13 143 000	0	1 565 907	0.20	7 829 534	978 692	62.5	587 215	37.5
1994	1 803 460	75 628	5 774 020	13 143 000	0	1 879 088	0.24	7 829 534	1 174 430	62.5	704 658	37.5
1995	2 038 346	75 628	5 774 020	13 143 000	0	2 113 974	0.27	7 829 534	1 321 234	62.5	792 740	37.5
1996	2 613 751	48 291	5 764 020	6 308 640	0	2 662 042	0.34	7 829 534	1 663 776	62.5	998 266	37.5
1997	2 926 932	48 291	5 764 020	6 308 640	0	2 975 223	0.38	7 829 534	1 859 514	62.5	1 115 709	37.5
1998	3 240 114	48 291	5 764 020	6 308 640	0	3 288 404	0.42	7 829 534	2 055 253	62.5	1 233 152	37.5
1999	3 396 704	48 291	5 764 020	6 308 640	0	3 444 995	0.44	7 829 534	2 153 122	62.5	1 291 873	37.5
2000	3 553 295	48 291	5 764 020	6 308 640	0	3 601 586	0.46	7 829 534	2 250 514	62.5	1 350 595	37.5
2001	3 631 590	48 291	5 764 020	6 308 640	0	3 679 881	0.47	7 829 534	2 299 926	62.5	1 379 955	37.5
2002	3 709 886	48 291	5 764 020	6 308 640	0	3 758 176	0.48	7 829 534	2 348 860	62.5	1 409 316	37.5
2003	3 788 181	48 291	5 764 020	6 308 640	0	3 836 472	0.49	7 829 534	2 397 795	62.5	1 438 677	37.5
2004	3 788 181	48 291	5 764 020	6 308 640	0	3 836 472	0.49	7 829 534	2 397 795	62.5	1 438 677	37.5
2005	3 866 476	48 291	5 764 020	6 308 640	0	3 914 767	0.50	7 829 534	2 446 729	62.5	1 468 038	37.5
2006	3 866 476	48 291	5 764 020	6 308 640	0	3 914 767	0.50	7 829 534	2 446 729	62.5	1 468 038	37.5
2007	3 866 476	48 291	5 764 020	6 308 640	0	3 914 767	0.50	7 829 534	2 446 729	62.5	1 468 038	37.5
2008	3 866 476	48 291	5 764 020	6 308 640	0	3 914 767	0.50	7 829 534	2 446 729	62.5	1 468 038	37.5
2009	3 866 476	48 291	5 764 020	6 308 640	0	3 914 767	0.50	7 829 534	2 446 729	62.5	1 468 038	37.5
2010	3 866 476	48 291	5 764 020	6 308 640	0	3 914 767	0.50	7 829 534	2 446 729	62.5	1 468 038	37.5
...	...	...	...	...	...	...	...	...	...	...	...	...
2018	3 866 476	48 291	5 764 020	6 308 640	0	3 914 767	0.50	7 829 534	2 446 729	62.5	1 468 038	37.5

1. IRR = 0.9517. 2. Gassi research station. 3. CFA francs 250 = US$ 1. 4. Office national de développment rural. 5. Action internationale contre la faim.

Table 17a. Sensitivity analysis with respect to the demand elasticity of sorghum.

Alternative values of the demand elasticity	NPV of benefits (US$ millions)	IRR
0.40	15.20	95.49%
0.35	15.15	95.34%
0.30	15.09	95.17%
0.25	15.03	95.03%
0.20	14.95	94.76%

Table 17b. Sensitivity analysis with respect to the supply elasticity of sorghum.

Alternative values of the demand elasticity	NPV of benefits (US$ millions)	IRR
0.60	15.13	95.29%
0.55	15.11	95.23%
0.50	15.09	95.17%
0.45	15.07	95.10%
0.40	15.04	94.03%

Table 17c. Sensitivity analysis with respect to the discount rate.

Alternative values of the demand elasticity	NPV of benefits (US$ millions)	IRR
0.20	4.13	95.17%
0.15	7.52	95.17%
0.10	15.09	95.17%
0.08	20.62	95.17%
0.05	34.37	94.17%

Table 18. Average grain yield (kg ha^{-1}) of S 35 and farmers' best local sorghum varieties in Chad, 1990-95,

Variety	Guéra	Mayo-Kebbi	Chari-Baguirmi	All sites
S 35	1090	1190	1180	1150
Local variety[1]	710	780	810	760
Yield gain	380	410	370	390

1. The local variety to be replaced by S 35 was not uniform, but varied from village to village and farmer to farmer. The most popular local varieties in Chad include the series Djigari, Nadj-dadj, Kouran, and Wakas.

Source: Based on our survey data.

Table 19. Illustration of cereal trade deficit reduction on adoption of S 35 sorghum variety: the case of Chad.

Indicators	Guera,	Mayo-Kebbi	Chari-Baguirmi	Chad[1]
Average annual yield gain	380 kg ha^{-1}	410 kg ha^{-1}	370 kg ha^{-1}	390 kg ha^{-1}
Average annual S 35 area	10 465 ha	11 132 ha	9676 ha	31 273 ha
Average annual output gain	3977 t	4564 t	3580 t	12 196 t
Extra output: average value[2]	US$ 477 million	US$ 548 million	US$ 430 million	US$ 1464 million
Cereals importation				
1985-1990	-	-	-	54 000 t
1990-94	-	-	-	60 000 t
Actual period differential	-	-	-	6 000 t
Real period differential[3]	-	-	-	18 000 t
Deficit reduction in cereal trade	$477 million	$548 million	$430 million	US$ 1464 million

1. Chad here is defined over the three study regions alone.
2. The extra productions are valued at an average price index (120 CFA francs kg-1) for cereal import.
3. The real differential between the two periods is greater than the actual differential by the amount of the extra output associated with the use of S 35.

There is also a trade deficit reduction factor to the food-security dimension of the S 35 technology. The macroeconomic aspect of the food-security indicator is illustrated in Table 19, where the reduction in government budgets for the import of cereals between 1985-1990 and 1990-94 is estimated at about US$ 1464 million.

Technical efficiency indicator. The cost analysis of farm-level production indicated that by using the S 35 technology, farmers achieved a significant per unit production cost reduction (Tables 12, 13, 14, and 15). Farmers have become more efficient in their use of inputs on adoption of S 35. For example, on an average, a total of 12 man-days are required to harvest 760 kg of local varieties of sorghum; the same amount of labor can harvest 1150 kg of S 35 sorghum. The per unit production cost reductions were estimated at about 23 000 CFA francs t^{-1} (i.e., US$ 92 t^{-1}) for the Guera, 8000 CFA francs t^{-1} (i.e., US$ 32 t^{-1}) for Mayo-Kebbi, and 18 000 CFA francs t^{-1} (i.e., US$ 72 t^{-1}) for Chari-Baguirmi.

Conclusions and implications

Conclusions

This study highlights the importance of the germplasm spillover, i.e., the extent to which scientists and farmers in Nigeria, Cameroon, and Chad used a genetic material first developed in India. This is an important consideration in international agricultural research, as research activities are more often than not planned around mandate crops and agroecological zones that are found in different parts of the world. ICRISAT, for example, has six mandate crops [sorghum, pearl millet (*Pennisetum glaucum* (L) R. Br.), finger millet (*Eleusine coracana* (L) Gaertn), chickpea (*Cicer arietinum* L.), pigeonpea (*Cajanus cajan* (L.) Millsp.), and groundnut (*Arachis hypogaea* L.), which are of vital importance to the increasing populations of the semi-arid tropics of Asia, Africa, and Latin America.

The sharing of germplasm by national and international research institutions through collaboration and networking has been emphasized. This is particularly important for national agricultural research systems (NARS), especially the less endowed ones, which could take advantage of research on similar agroecological zones. The knowledge thus obtained could then be adapted quickly to the specific local environment at limited research costs. The successful introduction of the ICRISAT-based sorghum variety S 35 in Chad via Cameroon is an outstanding example of the advantages of international collaboration in the field of agricultural research. Because the S 35 material sent to Chad in 1986 was in an advanced form, NARS scientists at the Gassi research station were able to release the technology in 1989, a mere three years after adaptive research was begun. The very high returns that have resulted from the use of the material by thousands of small farmers in Chad are mainly due to

- the short R&D period
- the immediate release of the technology once it was developed
- the outstanding seed multiplication and distribution support organized by the FAO/UNDP-sponsored seed project at Gassi.

As the Gassi seed project is to be phased out, it is extremely important to come up with alternative sources of support in order to spread this wonderful sorghum technology further throughout rural Chad for the benefit of thousands of small-holders and poor farmers.

Implications

What do the results of this study imply for future sorghum improvement research in Chad? The estimated high returns have demonstrated that past sorghum research investments have been profitable, but say very little about the profitability or orientation of future sorghum research investments. For the formulation of future research priorities, it would be fruitful to analyze farm-level information, especially the constraints that have been identified by farmers.

Further adaptive research on S 35

Bird damage was cited as a major constraint to the adoption and intensive use of the S 35 technology. This is a clear indication that farmers do not fully understand the concept of appropriate sowing dates for the variety. Future research should strive to determine more appropriate sowing dates for the variety in each region and extension services should teach farmers how to delay their sowing dates.

Soil fertilization research. Although this constraint concerns only a limited number of farmers in specific zones (the Guera and Mayo-Kebbi), it must be taken seriously now, given trends in increasing population growth and the associated high pressure on land. Research to address this constraint should particularly focus on the following two areas

- appropriateness of soil fertilization techniques
- alternative uses of sorghum and postharvest technologies.

Given the current low-income level of the average farmer in Chad and the high cost of commercial fertilizers, it is important that research concentrates on simple but effective fertilization techniques that are based on raw materials available on the farms. Composting, use of crop residues, introduction of leguminous plants in the cropping systems, and the judicious application of mineral fertilizers are priority areas for soil-fertility research.

In order to invest in soil restoration and conservation technologies, it is important that farmers are able to pay for the required inputs. Given the current emphasis on structural adjustment and market liberalization, it is unlikely that input subsidies will be implemented to allow farmers easy access to commercial inputs. Sorghum farming should be perceived as a self-sustained activity that is worth investing in.

Research on postharvest technologies, leading to new uses of sorghum and improvement in current marketing channels, must be high on future research agendas. Currently, farmers tend to sell their sorghum to middlemen shortly after harvest, only to buy it back later on at two to three times the price. The marketing system of sorghum must be studied more carefully in order to allow farmers to benefit from the fruits of their labor and to enable them to reinvest in the restoration and conservation of their lands/soils for more sustainable sorghum-based production systems.

Seed sector research. The mini-dose strategy, consisting of packaging breeder seed into small bags of 250 g, 1 kg, and 5 kg and selling them to farmers, ONDR agencies, and NGOs has been adopted by Gassi scientists as an appropriate way of reaching many farmers more easily. Farmers are advised to sow the mini-dose in a small field near their homesteads (isolated from other sorghum fields) and use the harvest as seed for the following year. A new mini-dose must be bought to renew the pure seed stock every three years or so. This system requires that farmers planning on adopting the technology must wait at least one year before actually cultivating the variety since the seed must first be multiplied.

Nonadopting farmers in the Guera,(13%) and Mayo-Kebbi (18%) indicated that the mini-dose system does not effectively allow them to adopt the variety on larger areas when they want to do so. They were not interested in producing their own seed on small plots. They were not able to afford more mini-doses for immediate production as the mini-doses are sold at cheaper rates to ONDR and NGOs than to farmers (Table 10). This system in its current form does not accelerate the spread of improved seed. Therefore, the development of a more efficient seed production and distribution system is important for research and agricultural planning in Chad. Decision makers should look into the issue and create an environment conducive to private sector participation in building an effective seed sector for coarse cereals, in general, and sorghum, in particular. The food security of the poor in the Sahelian Zone depends on it.

Acknowledgments

We gratefully acknowledge the assistance we received from ONDR, especially from Mathias Ndormadingar, Chief of the Extension Division, for his immense help in collecting and piecing together cost information on ONDR's extension activities; Behiguim Gedeon, Administrator, A1CF, for his help in securing cost information on AICF's extension activities; Aboubacar Ousta, Director, DRTA, who lent us his service vehicle for field trips in the Guera; M C S Bantilan, S K Debrah, D Rohrbach, and B V S Reddy for critical and valuable comments on the first draft of the manuscript and D S Murthy for providing historical information on S 35 R&D. We would also like to acknowledge the assistance of D Hash in editing the manuscript and proof-reading the final drafts of the publication. Our debts are far too many to enumerate. Our apologies to all those whom we have been unable to mention here.

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Notes

Notes

Résumé

L'évaluation de l'impact économique de la variété de sorgho S 35 au Tchad. La variété de sorgho S 35 est une lignée pure tolérante à la sécheresse, peu sensible à la photopériode, à rendement élevé, et à maturation précoce. Cette lignée est provenue du programme de sélection de l'ICRISAT en Inde, et a ensuite été avancée et vulgarisée au Cameroun et au Tchad. L'introduction de cette variété dans les régions du Tchad susceptibles à la sécheresse a connue une grande réussite, avec une valeur nette actuelle des investissements de recherche évaluée à US$ 15 millions, ce qui représente un taux interne de rentabilité de 95%. Deux facteurs importants expliquent ce succès: 1. les retombées secondaires de recherche des programmes de sélection de l'ICRISAT et du Cameroun ont permis une réduction importante des délais entre la recherche et le développement du S 35 au Tchad; et 2. le projet semencier soutenu par le PNUD/FAO à Gassi a non seulement multiplié avec succès les semences de S 35 à grande échelle, mais il a rendu possible la distribution des semences aux paysans en adoptant l'approche "mini-doses" et avec la participation de l'Office national de développement rural et les organisations non-gouvernementales.

Les pratiques d'exploitation préconisées pour l'adoption de la S 35 sont simples et relativement facile à mettre en place avec la main-d'oeuvre disponible en famille et avec la traction animale. En outre, elles ne demandent pas d'investissements importants. Par conséquent, cette technologie a été très favorisée par beaucoup de paysans. Entre 1990 et 1995, le pourcentage des paysans adoptant cette technologie est passé de 14% à 80%. En 1990, 7% de la superficie totale du sorgho (13 000 ha) a été couverte par la variété S 35. Vers 1995, la superficie consacrée à la S 35 avait augmenté à 27% (66 000 ha). Un avantage de rendement d'environ 51% par rapport aux variétés locales des paysans est associé à l'adoption de la S 35.

Les trois contraintes majeures citées par les paysans – la sensibilité de la variété à l'attaque par les oiseaux, le coût élevé des semences et la fertilité réduite du sol – devraient faciliter l'élaboration des priorités futures de recherche.

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ICRISAT's mandate crops are sorghum, pearl millet, finger millet, chickpea, pigeonpea, and groundnut; these six crops are vital to life for the ever-increasing populations of the semi-arid tropics. ICRISAT's mission is to conduct research which can lead to enhanced sustainable production of these crops and to improved management of the limited natural resources of the SAT. ICRISAT communicates information on technologies as they are developed through workshops, networks, training, library services, and publishing.

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ISBN 92-9066-408-8 Order code ISE 006 200-99