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Agricultural Research Impact Assessment: The Case of Maize Technology Adoption in Southern Mali

by

Duncan Boughton and Bruno Henry de Frahan

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Department of Economics
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AGRICULTURAL RESEARCH IMPACT ASSESSMENT: THE CASE OF MAIZE TECHNOLOGY ADOPTION IN SOUTHERN MALI

by

Duncan Boughton and Bruno Henry de Frahan*

June 1994

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*The authors are, respectively, Research Associate, Department of Agricultural Economics, Michigan State University, U.S.A., and Professor, Department of Agricultural Economics, Catholic University of Louvain, Belgium.

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To the success of the efforts of all Malians who seek to promote the good of their fellow men and women through agricultural development, this report is respectfully dedicated.

EXECUTIVE SUMMARY

The Malian agricultural research service was established in 1961, and a rainfed cereal varietal improvement program began in 1964. Historically maize has remained a very minor part of the total research effort. Major emphasis has been on varietal selection, initially focussing on linkages with French-operated research stations in West Africa, and more recently linkages with regional and international centers/networks (CIMMYT, SAFGRAD, IITA). During the 1980s there was also a strong emphasis on the development of maize-based intercropping technology (in particular maize-late millet intercropping).

The initiative to promote improved maize was taken by the cotton parastatal, the Compagnie Malienne pour le Développement des Textiles (CMDT), in response to chronic food deficits during the mid-1970s. The CMDT promoted a sole maize package consisting of an improved local variety, identified during the period of the colonial administration, and a set of husbandry practices (time of planting, planting density, fertilization) based on research findings generated in other West African countries (Senegal, Burkina Faso, Côte d'Ivoire). Additional varieties were released over time, including a streak-resistant variety from IITA.

Adoption of the improved maize package was particularly rapid during the period 1980-86 when an attractive guaranteed price was offered and extension activities were reinforced by a maize project that included the establishment of a seed multiplication program. Following cereal market price liberalization in 1986, maize prices fell and have been subject to considerable variability. Area has continued to expand, but farmers have greatly reduced fertilizer use, switched back to maize-late millet intercropping, and substituted early maturing varieties better suited to their own food security needs.

The estimated internal rate of return (IRR) to investment in maize research and extension in southern Mali over the period 1969-90 is 135%. This high rate can be attributed to low research costs (much of the technical package was borrowed from research conducted elsewhere in West Africa), and the high economic value of maize as an import substitute. Sensitivity analysis indicates that the IRR is robust with respect to adverse changes in assumptions concerning overvaluation of the exchange rate, research costs, extension costs, and area of improved maize. It is moderately sensitive to price and yield reductions.

The high IRR achieved in the past to a focussed, integrated maize technology delivery system is not necessarily a guide to future returns. Market opportunities beyond assuring food security during the "hungry season" are limited due to the lack of low-cost processing technologies.

LIST OF ACRONYMS

CEMP	Cellule des Essais Multilocaux et Prévulgarisation (IER)
CIF	Cost, Insurance, and Freight
CIMMYT	International Wheat and Maize Improvement Centre
CFAF	CFA Franc, currency unit used by member countries of the West African Monetary Union, of which Mali is a member; convertible with the French Franc at 1 FF = 50 CFA
CFDT	Compagnie Française pour le Développement des Fibres Textiles
CMDT	Compagnie Malienne pour le Développement des Textiles
DPAER	Département de Planification Agricole et Economie Rurale (IER)
DRSP	Département de Recherche sur les Systèmes de Production (IER)
ERO	Exchange Rate Overvaluation
FOB	Free on Board
GRM	Gouvernement du République du Mali
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IER	Institut d'Economie Rurale
IITA	International Institute for Tropical Agriculture
IRAT	Institut de Recherches Agronomiques Tropicales et Vivrières
IRCT	Institut de Recherches du Coton et des Textiles Exotiques
INB	Incremental Net Benefit
IRR	Internal Rate of Return
NPV	Net Present Value
OHV	Opération Haute Vallée
ODR	Opération de Développement Rurale
OPAM	Office des Produits Agricoles du Mali
PRMC	Programme de Restructuration du Marché Céréalier
RD	Recommendation Domain
SAFGRAD	Semi-Arid Food Grains Research and Development Project
SRCVO	Section de Recherche sur les Cultures Vivirières et Oléagineuses (IER)
USAID	United States Agency for International Development

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1. Background to the Study

The case of maize in Southern Mali is one of seven agricultural research impact studies being undertaken in Africa for USAID (AFR/ARTS/FARA) under the Food Security in Africa Cooperative Agreement. Maize was chosen because of its high agronomic potential, well-defined geographical area of cultivation, and evidence that research had generated some tangible results in the form of improved varieties. At the initial design stage, the prevailing view among host-country research and extension staff was that the cultivation of intensive maize experienced a boom during the early 1980s when there was a guaranteed market, but that it subsequently collapsed when prices were liberalized. Since this was an experience that might occur in the future for other commodities, given the market reforms currently under way in Mali and elsewhere in Africa, it was decided to link the impact assessment to a broader study of the maize subsector. This would not only enable the team to understand better the historical constraints to the impact of maize research and extension in southern Mali, but also to identify the kinds of technological, institutional and policy-related innovations that could enhance the future contribution of the maize subsector to agricultural and economic development in Mali.

The impact assessment study was initiated in July 1991 in collaboration with the Farming Systems Department (DRSP) of the national research program. The maize subsector study was initiated in January 1992 with the Planning and Rural Economics Department (DPAER).[1] In addition, the study received strong collaboration from the two regional development organizations in the study area, the Compagnie Malienne pour le Développement des Textiles (CMDT) and the Opération Haute Vallée (OHV). In particular, the authors received valuable assistance from Almoustapha Diop of OHV, who is currently completing an M.S. degree at North Carolina A & T University using data on technology adoption in the OHV zone collected in the course of this study.

1.2. Study Objectives and Methods

In collaboration with the DRSP, the study objectives were formulated as a logical sequence of questions:

(1) What technologies have been developed and diffused for maize over the last ten to fifteen years?
(2) What technologies have been accepted, rejected, or modified by farmers, and why?

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[1] The DPAER has recently been entrusted with the mandate to undertake commodity subsector studies in order to help guide research priority setting and facilitate coordination of research activities at different stages in the subsector. The maize subsector study is the first such study to be undertaken and is regarded as a pilot study with a strong emphasis on developing cost-effective and timely methods. The DPAER will also have responsibility for the monitoring and evaluation of research activities.

(3) What has been the impact of maize technology adoption at the farm household level?
(4) What factors have encouraged and what factors have constrained the adoption of maize technology at the farm household level?
(5) What is the profitability, or rate of return, to investment in maize research and diffusion at the national level?
(6) What factors have encouraged and what factors have constrained the rate of return to investment in maize research and diffusion?

With only slight modifications (such as the historical time span of maize technology development) these six questions provided a guide throughout the duration of the study.

The first question involved documenting maize research and extension activities since the late 1970s through literature review (annual reports of research and extension agencies in particular) and in-depth interviews with the researchers and extension workers involved.

Questions two through four focus on the farm-level impact of maize technology and were addressed through the analysis of secondary data from extension agencies, complemented by informal surveys with farmer groups and detailed interviews with extension workers. Topics discussed include the following:

- existing varieties and cultural practices for maize, changes that have occurred over time and source of the changes, advantages and disadvantages of new varieties/practices, modifications to recommended practices that farmers have made and reasons for those changes;
- changes in area cultivated and cropping pattern, availability and mix of food grains, changes in cash income, changes in food preferences, effects on soil fertility;
- how adoption of technology has been affected by climatic changes, availability of animal traction, availability of seed and other inputs, price supports, access to markets, storage, and processing facilities.

Subsequently, financial crop budgets for different recommendation domains were developed using secondary data on the adoption of husbandry practices in the CMDT and OHV zones.[2] Once the farm-level impacts had been determined, questions five and six on the economic impact of maize technology development and extension could be addressed. A benefit/cost analysis was undertaken, whereby economic prices were applied to the different crop enterprise budgets and then net benefits were aggregated over the area of improved maize cultivated in each recommendation domain over time. Costs were estimated by examining the historical expenditures of relevant institutions (IER, OHV, CMDT) and the proportion of expenditures that could be attributed to maize. A detailed explanation of the procedures is provided in section 5.

[2] A recommendation domain refers to a group of farmers utilizing similar husbandry practices for maize under similar agro-climatic conditions. The process of identifying different recommendation domains is discussed in detail in section 5.

2. OVERVIEW OF THE MAIZE SUBSECTOR IN MALI

Given the decision to evaluate the impact of maize research in the context of a commodity subsector approach, we begin with a descriptive analysis of the maize subsector (figure 1).

Historically, maize research has been a relatively minor part of the total agricultural research effort. Since the early 1970s, the primary focus has been on varietal selection, initially based on linkages with French-operated research stations in West Africa and more recently on linkages with regional and international centers/networks. During the 1980s, FSR/E teams made significant efforts to improve traditional maize-based intercropping technology (in particular maize-late millet) but without success. Extension services are provided by two parastatals, the Opération Haute Vallée (OHV) and the Compagnie Malienne pour le Développement des Textiles (figure 2). The supply of agricultural inputs has been liberalized, although the CMDT remains the main supplier of inputs because bulk purchasing and back haulage (trucks returning from cotton delivery to the Ivory Coast) permit lower input delivery costs than the private sector. Credit for the purchase of inputs is supplied by an agricultural bank, and the supervision of disbursement and recovery is increasingly being undertaken by village associations.

At the farm-level production stage, maize represents about 5%-10% of the total cereal area in Mali, and about 10%-15% of cereal production. At a 7% rate of growth of output, it is also the most rapidly growing cereal subsector (Holtzman et al. 1991). Approximately 80% of the total Malian maize crop is grown in the study area, where rainfall ranges from an average of 1200 mm in the south to 700 mm in the north. Fresh maize plays a vital role as a hungry season food as early as mid-July and is very popular in roasted form among urban dwellers. Consequently, it can be a valuable cash crop for farmers in peri-urban areas with good access to urban markets. Grain maize, available from the end of September, continues to be a key food source for rural consumers through to the arrival of the millet/sorghum harvest in November. Maize stover is generally left in the field and consumed by livestock during the dry season.

Farm-level storage is generally not a problem, partly because most of the crop is consumed in a relatively short period and partly because it is stored on the ear, making it more difficult for insects to penetrate the grains.

The marketing of maize grain takes place through the same network of rural collectors and wholesalers, transporters, and urban wholesalers and retailers as other coarse grains.[3] Quantities marketed through these channels are small relative to millet and sorghum, and relative to the total maize harvest since much is eaten fresh. The quantities marketed also vary considerably from year to year according to the size of the maize and millet/sorghum harvest.

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[3] Fresh maize is marketed largely by merchants who handle other vegetables as well. The description that follows focusses on the maize grain subsector.

Figure 1. The Maize Subsector in Mali

Figure 2. The CMDT and OHV Zones of Southern Mali

If the millet/sorghum harvest is poor, then maize marketings will be low even if the maize harvest was good as farmers substitute maize for millet and sorghum in their diet. Most maize marketed beyond rural markets goes to the capital, Bamako. In deficit years, maize is also marketed via Bamako to Kayes and Nioro.

In general, the marketing system is competitive but costly. The average marketing margin of 35 CFA/kg ($0.17/kg) between the producer price in Koutiala (a rural assembly market in the CMDT zone) and retail markets in Bamako represents approximately 50% of the average price paid by consumers. However, the high correlation between prices in rural markets and Bamako retail prices suggests that this margin is not due to a lack of competition among traders. Rather it is indicative of the high assembly and transportation costs that result from small, dispersed quantities of marketed produce, poor rural infrastructure, the risk inherent in trading in a volatile market, and the high cost of vehicles, fuel, and spare parts.

Only very limited quantities of maize are stored off-farm. The majority of traders are cash constrained and therefore seek profits from turnover rather than from speculative storage. Furthermore, storage at merchant level presents more difficulties than farm-level storage because the maize is in grain form and therefore more vulnerable to insect infestation. Finally, the possibility of imports from Côte d'Ivoire Coast (where the maize harvest is earlier) effectively places a price ceiling on maize, limiting potential profits to storage.

Processing represents a major constraint to maize consumption. In rural areas, maize is both dehulled and milled using pestle and mortar since mechanical processing is very costly relative to rural women's incomes (ATI 1992). In urban areas, maize is usually dehulled manually and then taken to a small custom mill for grinding into flour (Holtzman et al. 1991). Virtually no pre-processed products (e.g. flour) are available in regular supply, with the exception of high quality maize grits, ground manually, as a breakfast cereal or desert for relatively wealthy urban consumers. Food aid shipments of degermed cornmeal periodically find their way to the Bamako market, but the supply is irregular. Human consumption of grain maize is mainly in the form of tô (a thick porridge made from flour and consumed mainly in the evening), bouillie (a thin porridge consumed at breakfast or supper), or couscous. In contrast to urban consumers in other African countries, Bamako consumers prefer yellow maize.

Consumption of maize grain by livestock is mainly limited to a rapidly expanding urban poultry subsector. These enterprises are almost entirely confined to egg-laying units, since intensive broiler production cannot compete with free range birds from rural areas. Poultry rearers also have a strong preference for yellow maize since this affects the color of egg yolks. Maize is also used in small quantities for the manufacture of pre-mixed feed for dairy cows. Industrial uses of maize are extremely limited and are likely to remain so in the medium term. These include flour for battery and glue manufacture, and grits for brewing.

3. BRIEF HISTORY OF MAIZE RESEARCH IN MALI

In 1961, the Malian Agricultural Research service was established with responsibility for ensuring coordination among organizations undertaking research in Mali. Prior to this date, most agricultural research had been carried out under the auspices of the Centre Fédéral de Recherches Agronomiques de Bambey (in Senegal) and the Office du Niger.[4] In the case of maize, varietal work had been limited to the application of mass selection procedures to local ecotypes (Le Conte 1965). This activity had resulted in the standardization of a local, early, yellow-grained variety called Zanguereni (85 days).

In 1962, a technical assistance agreement was concluded between GRM and the Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières (IRAT), a French tropical research institute created in 1960. IRAT was to take responsibility for soil science, rice, and wheat varietal improvement, and research on industrial crops and sugar cane. In 1964, this agreement was amended to include the creation of a varietal improvement program for rainfed cereals (IRAT 1974).

3.1. Initial Establishment of a Rainfed Cereal Crop Varietal Improvement Program (1964-80)

Responsibility for rainfed cereal (millet, sorghum, maize) varietal improvement was entrusted to IRAT from the program's inception in 1964 until 1974. The human and financial resources devoted to IRAT's program in Mali appear to have been small relative to other West African countries (in particular Senegal and Burkina Faso). Maize was allocated only a small part of these resources in view of the limited area cultivated relative to other rainfed cereals: "Compte tenu de la modicité de ses moyens, en personnel spécialisé notamment, de la dispersion de ses structures, des priorités à respecter, l'IRAT a consacré peu d'efforts à cette plante." (IRAT 1974, 33)

Research on maize was largely confined to varietal testing, with a limited amount of work on fertilizer use in the context of a broader study of the fertilization of rainfed cereals. A varietal evaluation program involving crosses between the improved local variety Zanguereni and varieties from the United States of America and Israel, initiated at M'Pessoba in 1962, was continued but without success (Sapin 1982). In addition to the limited amount of varietal work, four trials involving the use of chemical fertilizer on maize were carried out during this period. The results indicated that, given prevailing prices of cereals and fertilizer, moderate doses of nitrogen and phosphate had every chance of being profitable on maize, marginally profitable on

[4] The two exceptions to this generalization are cotton research, conducted at M'Pessoba by IRCT from 1925 onwards, and livestock research, begun in 1927 with the establishment of a livestock farm at Sotuba, which subsequently grew into a major livestock research station for the Sahel by 1950 (Shetty, Beninati, and Beckerman 1991).

sorghum, and not profitable on millet. For maize, a binary formulation of nitrogen and phosphate was recommended (Piéri 1973).

Interest in anything more than a token effort to develop maize production first became apparent at the annual meeting of the National Agronomic Research Committee in April 1969. At that time, maize cultivation was limited to small plots around the farm household, and a limited area of flood recession cultivation in the Senegal river valley, with yields estimated to be in the range 600 - 1000 kg/ha. The committee's interest appears to have been stimulated in part by a project proposal from the Direction des Industries to consider a range of possible industrial uses of maize.[5] The project was considered premature because of the uncertainty surrounding the feasibility of large-scale intensive maize cultivation. Nevertheless, given the value of maize as a food crop, its agronomic potential, and the lack of progress made in regard to the intensification of millet and sorghum, the committee considered that greater effort should be devoted to maize research than had been the case hitherto (IRAT 1974).

To give effect to the National Agricultural Research Committee's conclusion, a renewed effort at varietal development began in 1969. The Israeli and U.S. exotics initially tested in the early 1960s were once again crossed with a local variety, this time the high yielding Tiémantié de Zamblara.[6] Hybrid varieties from Burkina Faso and Senegal were also included in the evaluation. However, none of these crosses proved to be significantly higher yielding than Tiémantié.

The main thrust of the research effort throughout the 1970s continued to be varietal improvement. The program was developed in close collaboration with the maize improvement programs at Farako-Ba in Burkina Faso, and Bouake in Côte d'Ivoire. The strategy chosen by IRAT researchers was to exploit to the maximum extent possible the genetic potential of West African ecotypes (Le Conte 1965). Accordingly, collections of local Malian ecotypes were made by Le Conte in the Sikasso area in 1971, and again in early 1974 throughout the maize growing areas of Mali. The collection made in 1971 was used, together with eight ecotypes from Burkina Faso, to create a composite variety, IRAT 85, at Farako-Ba. This West African composite was in turn used for crossing with exotics, some of which were subsequently tested in Mali.

The 1974 collection was used to create a Malian composite variety. However, none of the open-pollinated varieties tested during this period were able to consistently outperform the local check

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[5] The possible industrial uses of maize appears to have been a subject in vogue at the time. See, for example, Miche 1971.

[6] This variety is usually referred to simply as Tiémantié, a Bambara word meaning "middle" or "intermediate." Zamblara is a village near Sikasso in southern Mali. Tiémantié was identified in Le Conte's 1971 collection of local ecotypes. It was placed in an observational trial in 1972, purified in 1973 and 1974, and released to the ODRs for multiplication in 1975.

Tiémantié, which proved to be not only high yielding but relatively stable as well.[7] Although complex hybrids were included in the varietal trials, and some (e.g. IRAT 81) performed quite well, researchers were hesitant to recommend their use due to the absence of a capable seed multiplication structure (IER 1982a). In the absence of any breakthrough with local ecotypes, the arrival of improved composite materials from CIMMYT in 1979 was a welcome development for the varietal testing program.

Despite recognition of the potential of maize by the National Committee for Agronomic Research in 1969, research efforts continued to be hampered by lack of resources during the 1970s.[8] The strategy of focussing most of the maize research effort during the 1970s on varietal improvement failed to result in any significant breakthrough. By the end of the decade, the need for a broader approach to the development of maize production potential had been recognized:

> On considère trop souvent l'utilisation d'une nouvelle variété comme la solution à un problème de développement, la selection comme une recette. La variété est un facteur, et pas toujours le plus important, parmi l'ensemble des facteurs de production à améliorer: cela explique que les recherches maïs de l'Institut se veulent pluridisciplinaires, s'intégrant dans une optique 'système de production.' (IER 1982b, 17)

The lack of resources devoted to maize research in Mali was offset to a considerable extent by the opportunity to benefit from research carried out by IRAT in other West African nations, including Benin, Côte d'Ivoire, Burkina Faso, Senegal, Togo, and Cameroon. Indeed, very little of the research on which the first extension bulletins for maize were based was carried out in Mali.[9] For improved husbandry practices, table 1 shows the principal countries where research was undertaken. In sum, while the 1970s did not produce the varietal breakthroughs hoped for, the use of research findings from other parts of the region, combined with the high potential of local varieties (particularly Tiémantié), meant that the elements of a technical package were nevertheless in place by the end of the decade.

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[7] Selection criteria applied during this period were as follows:
- (i) flint or semi-flint, yellow or white maize;
- (ii) duration 80-120 days;
- (iii) high-yielding open pollination;
- (iv) resistant to lodging or shattering;
- (v) average height of 2 - 2.5 meters.

[8] P. Sapin. Personal communication. December 1991.

[9] Michel Fok. Personal communication. October 1991.

Table 1. IRAT Maize Research in West Africa (1962-79)

RESEARCH THEME	COUNTRY
Soil preparation techniques	Benin, Côte d'Ivoire, Burkina Faso, Senegal, Togo
Seedbed preparation	Senegal, Côte d'Ivoire
Data of planting	Benin, Cameroon, Senegal
Planting density	all countries
Crop rotation	Benin, Burkina Faso, Senegal, Côte d'Ivoire

Source: Nicou (1981)

3.2. Towards an Integrated Approach to Maize Research (1980-Present)

The 1980s saw a considerable increase in the scope of maize research activities, the number of disciplines involved, and in the extent of linkages with national and international organizations. Research into improved maize-based intercropping systems was initiated on-station by a team of ICRISAT and local scientists. A package was subsequently tested on-farm by the SAFGRAD project and farming systems teams based at Sikasso and Bougouni in the CMDT zone, and at Sotuba in the OHV zone.[10] A serious outbreak of maize streak virus in the CMDT zone in 1983 prompted a major, and successful, combined effort by researchers from varietal development and crop protection and staff of the CMDT's Cellule Recherche d'Accompagnement. This experience had a lasting effect on collaboration between the CMDT and IER in regard to maize research and development that continues to this day.

3.2.1. Varietal Development

The diversification of sources of maize germplasm, which began at the end of the 1970s with the arrival of CIMMYT material, continued through the 1980s. As the decade progressed, emphasis was increasingly placed on disease resistance and early maturity as selection criteria. Disease resistance became prominent as a selection criterion following a dramatic outbreak of maize streak virus in the southern part of the CMDT zone in 1983. The emphasis on early maturity was a response to the needs of farmers in the central and western parts of the country where rainfall is lower, and non-mechanized farmers for whom early harvested maize remains a key part of their hungry season food security strategy. The importance of early maturity was also emphasized in feedback from a program of on-farm tests of promising varieties, initiated by the

[10] The SAFGRAD project was partially funded and the ICRISAT and OHV farming systems projects wholly funded by USAID. While maize has not been a central focus of these projects, they nevertheless considerably increased the scope and application of maize research at farm level. The present maize varietal improvement program leader received M.S. level training at Iowa State University under the SAFGRAD project.

Semi-Arid Food Grains Research and Development (SAFGRAD) project in collaboration with regional development agencies. The CMDT's maize project, which began in 1980 with funding from the French cooperation program, also undertook on-station and on-farm varietal evaluation.

Compared to the previous decade, an impressive list of ten varieties was nominally available to the farming community by the end of the 1980s. However, of these, one (Tiémantié) had been available since before independence, three were extended directly by the CMDT (Tuxpeno 1, Molobala 2, E211) without IER involvement, and two (Across 7844 and Golden Crystal) have yet to be disseminated in the OHV because registered seed was not available from the national seed multiplication service. Furthermore, all external introductions (except Golden Crystal, which is not available) are white, whereas the preference of urban consumers and poultry rearers is for yellow.

Despite these weaknesses, progress made in varietal development during the 1980s was dramatic compared to that made during the 1970s. In particular, the identification and release of the streak resistant, early-maturing TZESR-W in less than four years was an astounding achievement and the result of intense collaboration between both disciplines and structures (CMDT and IER). Informal discussions with farmers reveal that while TZESR-W was primarily selected for streak resistance, it is particularly appreciated for its early duration and ability to perform relatively well with only moderate doses of fertilizer. These traits have become more important to farmers since the withdrawal of a guaranteed maize price in 1986, which coincided with the dissemination of TZESR-W.

3.2.2. Maize-Based Intercropping Research

Maize-based intercropping systems have long been a part of the farming systems indigenous to southern Mali (Dolo 1987). Efforts to improve maize/millet intercropping were initiated on-station by ICRISAT during the early 1980s, and subsequently tested on-farm by the SAFGRAD project. Further on-farm testing was undertaken by the Farming Systems Research programs based at Sikasso and Bougouni for the CMDT zone, and at Sotuba for the OHV zone. The CMDT's Cellule Recherche d'Accompagnement also conducted demonstrations of improved maize-late millet packages.[11] Despite the significant manpower and financial resources devoted to the improvement of this traditional practice, no concrete evidence of farm-level impact has been established by the authors. It is important to understand the reasons for this lack of impact in order to identify ways of improving the effectiveness of future research endeavors. Not

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[11] Initially the CMDT's maize project was against intercropping, promoting a sole maize package. After the dramatic outbreak of maize streak virus in 1983, and after the drought spells of 1983 and 1984, CMDT staff realized that intercropped maize was more resistant to drought and disease problems than sole maize. In the case of streak virus, intercropped maize was less severely attacked than sole maize (which often suffered a complete wipeout). In the case of drought, the intercropped late millet yields would compensate for the loss of maize yield to some extent.

having been involved in any of this research, the authors can only raise questions and do not presume to be in a position to give definitive answers.

ICRISAT's work on maize/millet intercropping was undertaken from 1982 to 1989, and involved agronomy, varietal, and fertilization components (Shetty, Beninati, and Beckerman 1991). The ICRISAT research was initiated after staff observed that farmers' traditional intercropping practices suffered lower yield reductions than sole maize in the event of drought or disease attack.[12] The agronomic research led to a spacing recommendation of two rows of maize to one of millet, the latter sown when the maize plants reach the 3-4 leaf stage. This recommendation implies an increase in the population of millet from 10,000 plants/ha (farmers' practice) to 30,000 plants/ha.[13] The varietal and fertilization research did not lead to any modification to existing recommendations for sole maize.

The improved maize-millet intercropping system was tested on-farm for four consecutive years from 1984 to 1987, first by the SAFGRAD project and subsequently by its successor unit within SRCVO, the Cellule des Essais Multilocaux et Prévulgarisation (CEMP). After three years of on-farm tests, SAFGRAD researchers concluded that the maize/millet intercropping system was higher yielding and more stable than either sole maize or millet, that the improved method of planting in alternate rows was higher yielding than the traditional practice of mixing the crops in the row, but that the system of planting in alternate rows was more difficult to weed mechanically (Traoré, Daou, and Sangaré 1987). The authors recommended that additional research be undertaken to facilitate mechanical weeding of the alternate row system. The CMDT's Cellule Recherche d'Accompagnement encountered the same difficulty of mechanical weeding in their program of on-farm demonstrations (Dolo 1987). As a result of the difficulties encountered in mechanical weeding, the "improved" system was never extended by the CMDT.[14]

Two key questions need to be answered: First, why was the mechanical weeding problem caused by the narrow between-row spacing never corrected? And second, why has the improved system not yet been extended to non-mechanized farmers in the CMDT zone?[15]

A considerable amount of effort was also devoted to maize/millet intercropping by all three farming systems research units in operation at the time. The team based at Bougouni undertook

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[12] Maize and millet are a good combination from an agronomic perspective because the two cereals have complementary growth cycles which reduce competition for soil moisture and yet make full use of the longer rainy season experienced in southern Mali.

[13] S.V.R. Shetty. Personal communication. October 1991.

[14] As one CMDT extension worker expressed it, with more than a little irony, "Having taken so many years to reach the stage of mechanized farming, are we supposed to go and tell the farmer to pick up the hand hoe again?"

[15] The establishment of a research program to address issues relating to the mechanization of intercropping systems in general was a recommendation of an intercropping workshop held in Mali in 1987. The authors are grateful to Dr. Amadou Diarra, head of the DRSP, for bringing this to our attention.

on-farm trials between 1981 and 1985, and pre-extension tests during 1986 and 1987 following a workshop on maize-millet intercropping held in Sikasso in 1985. This research focussed on the two planting methods as well as different levels and types (mineral versus organic) of fertilizer application. In many cases the team found it difficult to draw definitive conclusions from the on-farm trials and tests because of operational difficulties. In general, fertilizer doses lower than those recommended by the CMDT were most profitable given farmers' practices.

The team based at Sikasso began work on maize-millet intercropping somewhat later than the Bougouni team, but focussed on similar technical themes (fertilization in particular). A synthesis of this work is currently being prepared. The farming systems team at Sotuba was not established until 1986 and hence was in a position to benefit from the work previously undertaken.

The farming systems team at Sotuba, anxious to avoid duplication of effort and to reduce the time taken to deliver technology to the farmer, chose to go straight into pre-extension of a maize-millet intercropping package. They did so on the basis that there was already a proven package available. This was clearly a false premise given the fact that the Sikasso farming systems team have not yet completed a definitive analysis of their on-farm research, the on-farm testing undertaken by SAFGRAD and the CMDT's Cellule Recherche d'Accompagnement had identified difficulties in mechanical weeding, and the CMDT was not actively extending any package for maize-millet intercropping. In the course of three years of on-farm tests the team ran into a number of setbacks which left them bemused and discouraged:

> L'association maïs/mil qui est assez performante dans la zone mali-Sud n'a pas fait preuve de cette performance en zone OHV. Par suite de la similarité entre la zone mali-Sud et la zone Sud et Est de l'OHV, l'association a été introduite. Le fait que les résultats n'ont pas été probants en zone OHV montre que le transfert latéral en matière de prévulgarisation ne marche pas toujours. Pour ce faire il s'agira de faire une étude diagnostique sur l'échec de cette association en zone OHV afin de savoir les principales contraintes avant de faire un feed-back à la recherche thématique. (IER 1992, 55)

The fact that one farming systems team could proceed with a pre-extension campaign on the basis that a proven package was available when other researchers had already encountered difficulties and/or had not yet completed a definitive analysis raises questions about the effectiveness of present procedures for the monitoring, evaluation, and communication of research activities.

Two important conclusions can be drawn from this review. First, while the on-station and on-farm research conducted to date has confirmed the strengths of the traditional practice of intercropping maize with late millet in southern Mali, there is no evidence of any farm-level adoption of an improved maize-millet intercropping system. The only distinctive element of the "improved" maize-millet intercropping system is the plant density/spatial arrangement, which has not been promoted by the CMDT because it cannot be weeded using animal traction. Rather than being attributable to any improved package, the rapid expansion of intercropped maize area in southern Mali in recent years reflects the traditional system's suitability to uncertain climatic and market conditions.[16] Such improvements in husbandry practices that have taken place at farm level appear to be primarily a spillover from earlier extension efforts to promote improved sole maize (e.g. plowing, fertilizer use, mechanical sowing).

The second conclusion that can be drawn is that there has been a considerable amount of duplication of research effort at the on-farm testing and "pre-extension" stages due to overlapping functions between different sections, and a lack of timely and effective communication of results. The CEMP, the CMDT's Cellule Recherche d'Accompagnement, and the three farming systems teams operating in southern Mali all have mandates for on-farm research.[17] The difficulties in effective communication of results between units is in part a reflection of the centralized and peer review process. These weaknesses are currently being addressed by a restructuring of IER which seeks both to decentralize the planning and review process, as well as emphasize development-oriented review criteria.

3.2.3. Crop Protection and Cultural Practices

Resources devoted to crop protection and cultural practices have been limited relative to other crops. With the exception of storage, maize in Mali has not encountered any significant insect pest challenges.[18] The bulk of the research on maize crop protection and cultural practices has therefore focussed on weed control, both mechanical and chemical. Herbicides identified as effective on sole maize were also verified for their suitability to maize-based intercropping patterns. A significant portion of research on herbicide evaluation is financed by the chemical companies.

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[16] Following the liberalization of cereal market prices in 1986, maize prices fell both absolutely and relative to millet and sorghum. Since 1986, millet prices have been consistently higher than maize prices in southern Mali, in part due to the export demand for millet from Côte d'Ivoire.

[17] This duplication has been noted by other observers. See Dembélé 1990.

[18] The outbreak of maize streak virus in 1983 prompted an intensive short-run effort to study the insect vector population dynamics in collaboration with the plant pathologist. The identification of a disease resistant variety (TZESR-W) appears to have eclipsed efforts to control of the vector by chemical or cultural means, both of which have drawbacks.

3.2.4. Accomplishments and Questions at Decade End

In sum, the 1980s saw both a broadening of maize research activities and significant efforts to bring them closer to the farmer. These developments are important not only in themselves, but also because they represent the emergence of vital long-term linkages between different research disciplines, between the national research and development organizations, and between the national and international research organizations. As such, they may be viewed as building up institutional capital (Bonnen 1990). The closer collaboration between the IER researchers and CMDT's Cellule Recherche d'Accompagnement following the outbreak of maize streak virus is a case in point.

Yet the 1980s came to a close with a number of key issues unresolved in regard to maize research. Several improved maize varieties have been recommended for extension to farmers, but their adoption has been severely restrained by the lack of seed multiplication and delivery systems.[19] The same constraint has prevented the use of hybrid varieties, which have been dismissed as too costly to produce despite the absence of any economic assessment on which to base such a conclusion. Researchers claimed to have developed an improved maize-millet intercropping system, but currently this system is neither being extended by the CMDT—because it does not permit mechanical weeding—nor corrected by research. A question mark also surrounds the cost-effectiveness of fertilizer recommendations for maize used by the CMDT and OHV, neither of which accord with the fertilizer dose favored by IER's fertilizer agronomist.

The purpose in raising these issues is not to argue for or against a given position (e.g. whether hybrids should or should not be extended to farmers), but rather to underline the fact that they need to be resolved. The benefits of agricultural research are only realized when agricultural technology is adopted by the farmer, not before. Consequently, the failure to disseminate improved varieties represents a lost opportunity to realize benefits for producers and consumers. So long as the weeding problems of the maize-millet intercropping system remain unaddressed, the extension service will remain ambivalent concerning its promotion. If current fertilizer recommendations are unnecessarily expensive, they represent a disincentive to fertilizer use. The present lack of resolution reflects in part the lack of integration of economists in IER's program but, more generally, the difficulty of implementing effective monitoring and evaluation procedures in a rapidly changing organizational context. Both are priority issues in IER's current restructuring program.

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[19] The CMDT is an exception in this regard. However, while the self-contained seed multiplication and distribution capability of the CMDT may have enabled it to get improved varieties into the hands of the farmers, it is not clear whether full use was made of the improved materials available from research. Hybrid varieties continued to be tested and unexploited despite the proven capacity of the CMDT's seed multiplication program.

4. THE DIFFUSION OF MAIZE TECHNOLOGY IN SOUTHERN MALI

The development of new technologies is not by itself sufficient for investments in research and extension to generate benefits for society. Farmers must adopt the technologies that flow from these investments. This requirement in turn implies that technological innovation must both enable farmers to further their objectives (e.g. income generation and/or enhanced food security) and be technically feasible and financially viable to implement. The high potential yields and early maturity of maize compared to sorghum or millet might lead one to consider the attraction of intensive maize production to be self-evident.

Maize offers no "free lunch," however. The husbandry requirements of a successful maize crop are demanding. The preparation of an adequate seedbed requires plowing for example, and the growing crop must be weeded regularly in the crucial early stages. In order to provide this level of husbandry, either a tractor or trained draft animals must be available. Intensive maize is also very demanding of soil nutrients, whereas the region's soils are generally infertile. The cultivation of maize on a scale beyond garden plots therefore requires the use of chemical fertilizer, which must be accessible in an appropriate form and profitable to use. This implies the development of input delivery, credit and crop marketing systems.

In sum, a set of complementary investments in physical and human capital, together with institutional and policy innovations, must be in place before farmers can adopt intensive maize technology on a wide scale. The critical role played by these factors is confirmed by a comparison of maize technology adoption in two areas of southern Mali that differ in their levels of physical and human capital investment (the OHV and CMDT zones), and within the same zone over time as the institutional and policy environment changes (the CMDT zone).

The remainder of this section is divided into two parts. The first part reviews the institutional background (organizations and policy) to the development of maize production in southern Mali. The second part documents the adoption process over time. Three distinct phases in the diffusion of maize technology are identified: the first phase concerns the period prior to any large-scale extension effort focussed on maize; the second deals with the period from the launch of the CMDT's *Projet Maïs* in 1980 until the liberalization of cereal prices in 1986; and the final phase covers the period from price liberalization up until the present day. The chapter concludes with an assessment of the contribution of agricultural research to this process.

4.1. Development and Policy Background to the Take-Off of Maize in Southern Mali

Two types of institutions play an important role in the development of maize production in southern Mali. The first are the Opérations de Développement Rurale (ODRs), government parastatals charged with rural development in a defined geographical area and generally having a particular cash commodity focus. The two ODRs charged with rural development in southern Mali are the Opération Haute Vallée (OHV) and the Compagnie Malienne pour le Développement des Textiles (CMDT). In both areas, cotton has been the vehicle for generating a cash surplus with which to mechanize and develop farming systems. The second dimension is government policy toward the production and marketing of cereals, which has undergone profound change in recent years. The two dimensions overlap in so far as the ODRs have historically been an important instrument for the implementation of food production and marketing policy.

4.1.1. Rural Development in Southern Mali: The CMDT Zone

The development of agricultural extension activities in southern Mali began in 1952 under the auspices of the Compagnie Française pour le Développement des Fibres Textiles (CFDT) (de Wilde 1969). Extension activities were confined to the promotion of cotton using a diffuse network of itinerant *moniteurs*. Following an agreement with GRM in 1960, which made the CFDT responsible for agricultural extension work in the greater part of southern Mali,[20] a denser, residential extension network was established. Although the CFDT's mandate was not confined to cotton, the company continued to focus on this crop: "It is clear that for the most part the improved production of cotton has been introduced without significantly affecting farming as a whole" (de Wilde 1969, 333). Nevertheless, the supply of agricultural equipment became an important part of the program, and over 13,000 plows and 3,000 carts were in use by 1964. This process of "capitalization" of the farming system, i.e. using the profits from cotton to pay for draft animals and equipment that subsequently permit an expansion of the cultivated area, is the hallmark of agricultural development in southern Mali.

The Compagnie Malienne pour le Développement des Textiles (CMDT) was created in 1974 to take over the activities of the CFDT while retaining close technical and commercial links with the latter. The CMDT was charged with a broader rural development mission than its predecessor. Specifically, its objectives include the following:

(1) to increase production of cotton and all crops grown in rotation with cotton in order to promote a biologically and economically balanced cropping system;
(2) to provide an effective agricultural extension service and credit for the purchase of equipment and other inputs necessary to raise income and improve food self-sufficiency;
(3) to improve the integration of livestock in farming systems;
(4) to train and educate the rural population by means of literacy training and the promotion of rural artisans and young farmers;
(5) to encourage the development of a network of village organizations (pre-cooperatives) to undertake tasks currently performed by resident extension workers;
(6) to enable advanced village associations to become independent cooperatives;
(7) to modernize farms through the gradual introduction of motorized equipment (small tractors);

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[20] The CFDT was made responsible for the greater part of eight districts (*cercles*) in the administrative regions of Bamako (Dioïla), Ségou (Ségou, San, and Tominian), and Sikasso (Koutiala, Yorosso, and Kadiolo).

(8) to promote farm management skills through the development of simple accounting methods;
(9) to process cotton and market the fibre;
(10) to develop the profitable use of agricultural by-products;
(11) to stock and market agricultural products according to policies in effect;
(12) to develop and promote appropriate technology for processing agricultural products. (CMDT 1990)

The existence of a competent development administration has encouraged a high level of donor support for the CMDT, including three World Bank financed rural development projects. This investment has facilitated the development of a network of rural roads while at farm-level the earnings from cotton have continued to permit the mechanization of farming systems and a rapid expansion of the cultivated area.

4.1.2. Rural Development in Southern Mali: The OHV Zone

The Opération Haute Vallée (OHV) is a smaller and younger organization, created in 1964. The comparative strengths and weaknesses of the OHV and the CMDT have been well documented by Dioné (1989, 41-45). He cites the following reasons for the superior performance of the CMDT compared to the OHV:

(1) higher participation of farmers in rural development activities through the transfer marketing functions to village organizations;
(2) linkages with the French cotton development organization (CFDT) facilitates access to research results, marketing channels, and credit;
(3) after the dismantling of the agricultural credit and rural equipment parastatal (SCAER), the CMDT was the only ODR with direct access to purchased farm inputs and agricultural equipment.

Dioné reports that "an estimated 75% of the CMDT farms have animal traction equipment against only 43% in OHV, and that the CMDT ensures an equipment replacement rate of 10-15%" (ibid.) as compared with virtually no replacement in the OHV zone. The CMDT also has a stronger extension program. In sum, the process of human and physical capital development necessary as a complement to rapid technological innovation was much further advanced in the CMDT zone than the OHV when maize was first identified as an important potential lever for raising cereal self-sufficiency in Mali. This brings us to the second dimension necessary to understanding the background to maize development, that of national cereals policy.

4.1.3. National Food Strategy and Cereal Marketing Policy

In response to chronic food deficits during the 1970s and early 1980s government policy has consistently stressed self-sufficiency in cereals as a policy objective. While the goal has remained essentially unchanged, there have been radical changes in the policies used to seek to achieve this objective. Steffen (1992) identifies three main phases in cereals marketing policy over the last twenty-five years: (1) a period of official state monopoly over cereals marketing (1967-81); (2) the coexistence of official and private marketing channels (1981-85); and (3) an effectively liberalized cereal market (1985-present). During the period 1965-85 both producer and consumer prices were fixed by decree. In general, official producer prices were held low in order to protect real urban wages (Steffen 1992). Competition from parallel market channels made it increasingly difficult for the national grain board (OPAM) to obtain cereals, which resorted to forcing producers to make deliveries. Nevertheless, OPAM rarely handled more than 20% of the total marketed surplus of cereals in Mali, with its market share of rice being higher than that of coarse grains (Humphreys 1986).

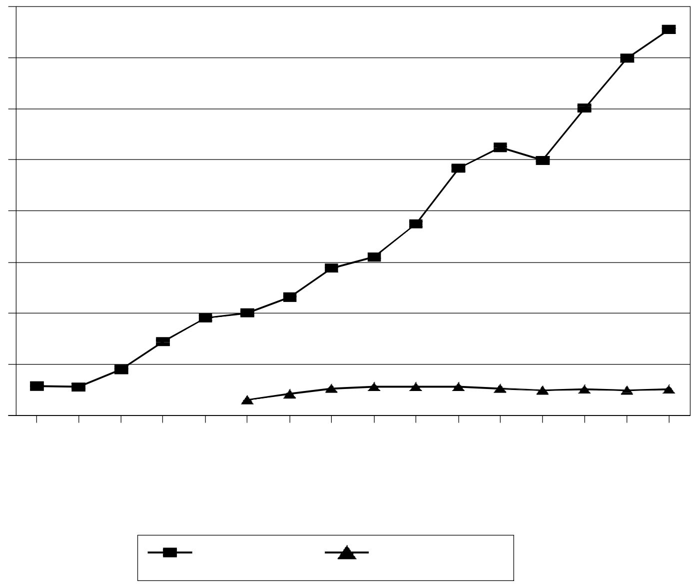
The growing financial deficits of OPAM were unsustainable, and in 1981 GRM and donors put together a Cereals Market Reorganization Project (PRMC) with three objectives: (1) rapid increases in producer prices; (2) cereal market liberalization through legalized participation of cereal traders; (3) the reduction of costly subsidies by allowing consumer prices to rise to the point where OPAM's costs were covered (Steffen 1992). Minimum producer prices replaced "official" producer prices and OPAM in effect became a buyer of last resort. Responsibility for the purchase of cereals from farmers on OPAM's behalf was transferred to the ODRs. It was this combination that enabled the CMDT, from 1981 onwards, to offer farmers an attractive guaranteed maize price. In 1985, however, there was a large cereal surplus which exhausted OPAM's financial reserves. With OPAM unable to make payments on grain the CMDT, in turn, was forced to suspend guaranteed prices to farmers.

4.2. Technology Adoption in the CMDT and OHV Zones (1975-90)

The decision by the CMDT to promote intensive maize production, in rotation with cotton, was taken against a background of chronic food deficits experienced during the early 1970s.[21] Initially promoted among farmers using small tractors, the program was quickly expanded to include farmers using animal traction. Adoption was rapid (figure 3). The two factors that underpin this phenomenon clearly demonstrate the significance for the rate of technology adoption at farm level of interactions between the stage of development of farming systems and market opportunities.

Figure 3. Adoption of Improved Maize in the CMDT and OHV Zones

[21] The term "intensive" here refers to the use of improved varieties and husbandry practices together with chemical fertilizers.



Source: CMDT and OHV Annual Reports

The stage of development of farming systems of Southern Mali had an important bearing on the rate of technology adoption. Since the late 1950s, the CMDT's predecessor (the CFDT) had been introducing mechanization as part of its program to expand cotton production. By the mid-1970s there were an estimated 110,000 draft oxen; 37,500 plows; 1,400 seeders; and 20,000 weeders in service. In 1990, the level of mechanization had increased to 305,000 draft oxen; 112,000 plows; 39,000 seeders; and 74,000 weeders. Farmers were able to pay for this equipment out of their profits from cotton production. Mechanization is crucial to a farmer's capacity to adopt intensive maize because of need to plow and weed frequently in a timely manner. Not surprisingly, the area of improved maize is highly correlated with level of mechanization over the period 1975-90.[22]

A second factor encouraging the adoption of maize was the availability of residual fertilizer on the previous year's cotton fields. Maize is the most fertilizer-responsive rainfed cereal, and the presence of residuals implies a lower cash outlay for farmers.

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[22] Bivariate correlations between the area of improved maize and the number of draft animals and equipment in service over the period 1975-90 gives the following results (all significant at the .01 level): number of draft oxen 0.98; number of plows 0.99; number of weeders 0.98; number of seeders 0.98.

While the level of mechanization and fertilizer residuals from cotton certainly facilitated adoption of maize at the outset, the process was greatly accelerated by the provision of an attractive guaranteed market price. With the transfer of responsibility for the purchase of cereals from the national grain board (OPAM) to rural development agencies, the CMDT was in a position to apply to maize the same integrated approach to technology delivery that it was already using so successfully for cotton. This approach ensured that all stages in the subsector both prior to farm-level production (seed multiplication and distribution, fertilizer and credit delivery, extension advice) and post harvest (purchase and collection, transport, storage, wholesaling) were coordinated through the administrative decisions and technical resources of a single organization.

The implementation of an integrated approach was strengthened by the launch of a maize development project in 1980. Financed by French aid, this project included the establishment and operational budget for a seed multiplication farm, a large-scale program of maize demonstrations (varieties and cultural practices), a program of first-equipment loans for non-mechanized farmers,[23] and the construction of maize storage silos at CMDT regional depots. Initially, the *Projet Maïs* gave little attention to linkages with research. With the exception of the variety promoted, which had been identified before independence, many other cultural recommendations were based on research findings from elsewhere in the region.[24] The project even went to the extent of conducting an independent program of varietal selection at the seed farm. The vulnerability of such an approach was clearly demonstrated by a dramatic outbreak of maize streak virus in 1983, which wiped out hundreds of hectares of the crop.

The national agricultural research program responded rapidly to the crisis. A cooperative program of plant pathology studies, together with screening for varietal resistance, was mounted by IER and the CMDT's Research and Development Liaison Unit at Sikasso (the institutionalized counterpart to the *Projet Maïs*). Within four years, the pathology of the virus was understood and early planting was identified as a cultural practice liable to reduce incidence of the disease. More importantly, since early planting of maize aggravates the labor bottleneck and increases the risk of drought at flowering time, an early-maturing streak-resistant variety of white maize had been identified, multiplied and made available to farmers. The success of this collaboration had an important impact on the relationship between IER and the CMDT, which has continued to contribute financially to the IER maize research program ever since.

[23] The *Projet Maïs* was conceived in part as a means to facilitate the development of farming systems in the less-developed southern part of the CMDT where cotton was not being promoted. Maize is preferable to cotton as a cash crop in low population density areas because of its lower labor requirements. Farmers in areas with low population density would find it difficult to organize sufficient labor to harvest cotton. In addition, as a dual-purpose crop, maize has advantage of reinforcing food security. While the objective of capitalizing the farming system through maize alone was doomed with the liberalization of cereal prices in 1986, even today farmers who receive first equipment loans (*prêts premier équipements*) are obliged to cultivate one hectare of maize in order to release labor from cereal to cotton cultivation without undermining food security.

[24] Michel Fok (formerly head of the *Projet Maïs*). Personal communication.

The joint impact of a coordinated subsector interacting with farming systems characterized by a high level of mechanization and a profitable cash crop on farmer adoption can be clearly demonstrated by comparison of the CMDT and OHV zones. The OHV did not put an integrated maize technology development program in place, and farming systems have considerably lower levels of mechanization. Consequently, the adoption curve for intensive maize in the OHV zone is almost flat (figure 3).

Although dramatically effective in terms of adoption rates, the integrated approach to maize production and marketing implemented by CMDT was not financially sustainable. It required high subsidies on the part of the national grain board (which purchased the maize from CMDT), and the CMDT itself was subsidizing village-level collection of maize. With the removal of guaranteed prices for maize in 1986 (accompanied by the withdrawal of credit for maize inputs) farmers were exposed to highly variable market prices. The farmers' response to this situation also underlines the importance of interactions between commodity subsector and farming systems.

While the combination of technology delivery in the context of a highly coordinated subsector and mechanized farming systems had a dramatic effect on the rate of technology adoption, the withdrawal of marketing services and guaranteed prices after 1986 primarily affected farmers' choice of production techniques. Although the area of improved maize quickly resumed its growth trajectory, farmers radically altered their choice of technology and degree of interaction with the market by the following measures:

(1) reduction in fertilization levels and substitution of manure for chemical fertilizer;
(2) substitution of early-maturing varieties tolerant of low soil fertility conditions for medium or long-duration varieties with high fertilization requirements;
(3) rapid shift from sole cropping back to the traditional practice of maize-millet intercropping (a system more tolerant of lower soil fertility and drought, and with a higher gross margin because millet sold at a higher price than maize);
(4) changes in marketing strategy: if the early maize harvest is good, and if the prospects for the millet/sorghum also look good, farmers will off-load their old millet and sorghum stocks on the market while prices are still high and eat maize instead.

In the face of erratic maize prices, and without a line of credit to purchase fertilizer, farmers effectively chose those technology options which enabled them to insulate themselves from the uncertainties of the market. Nevertheless, the continued expansion of maize production for on-farm consumption is an important contribution to improved food security in rural areas.

It would be difficult, if not heroic, to attempt to isolate the contribution of research from that of extension. Clearly in terms of initiative and resources devoted, the promotion of maize has been primarily an extension effort. Probably the most important contribution of research to date has been the identification of the streak-resistant early-maturing variety TZESR-W,[25] which has enabled farmers not only to confront disease but also to create a radically changed marketing environment. There is no evidence that the intercropping research carried out by IER has had any impact at farm level since the package was not promoted by the CMDT (because the farmers found the row-spacing too narrow for mechanical weeding). Nevertheless, the productivity of the traditional maize-millet intercropping system has undoubtedly been increased by the application of husbandry techniques initially learned by farmers through the earlier adoption of the sole maize package.

[25] A yellow counterpart to this variety, incorporating downy mildew as well as streak virus resistance (DMRESR-Y), will likely be made available to farmers in the near future.

5. COSTS AND BENEFITS OF MAIZE TECHNOLOGY DEVELOPMENT AND DIFFUSION

This section assesses the impact of maize technology development and diffusion by comparing the costs incurred with the benefits derived. The analysis is conducted at two levels. The first part of this section provides an analysis of the farm-level costs and benefits of improved maize technology in financial terms. The second part estimates the aggregate costs and benefits of maize technology development in Southern Mali in economic terms. The objectives and methods used for each level of analysis are described below.

5.1. Farm-Level Financial Analysis

One of the key questions we want to answer is the following: "What has been the impact of adoption of improved maize production technology at farm level?" An appropriate way to address this issue is to measure the additional costs incurred and benefits derived from the farmer's perspective. This requires the use of prices actually paid by farmers for inputs and received for marketed produce. These prices are referred to as financial prices, and analysis based on them is referred to as financial analysis. Financial prices differ from those used in economic analysis by the value of any taxes paid or subsidies received by farmers, including, in the case of traded commodities, those implicit in the official exchange rate.

Many inputs used by farmers, and much, if not all, of the additional maize produced may not be exchanged in the marketplace. Inputs may be provided, or produce consumed, by members of the farm household. In this case, a financial opportunity price is used to value the input or output. An opportunity price reflects the amount of money the household would have had to pay for an input, or could have received for produce, had it been exchanged on the market.

Some benefits and costs may not be measurable in financial terms. Take increased food security, for example. Many farmers state that the adoption of maize as a field crop[26] has reduced the likelihood of food shortage. The value of reduced risk of hunger to the farmer cannot be estimated in financial terms. On the cost side, farmers widely agree that maize is much more arduous for women to process than other cereals. Indeed it is often said that "maize causes divorce." There is evidently an additional cost borne by women, but it cannot be estimated on the basis of prices observed in the marketplace.

5.1.1. Methods Used for Farm-Level Financial Analysis

The analysis of farm-level financial benefits is carried out with partial budgets. A partial budget is a simple tool for estimating the net effect of a change in technology on household income. It

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[26] Prior to the promotion of maize as a field crop in the early 1970s, it was confined to small plots around the house called "*champs de case*," which were cultivated entirely by hand. These plots benefitted from a high level of organic matter, receiving kitchen waste and sweepings from the compound yard.

is "partial" in the sense that only those elements of the farm household's production and marketing activities which have changed as a result of technology adoption are compared. A partial budget used to estimate the net effect of fertilizer use on a given crop, for example, might include the additional cost of fertilizer, the additional cost of labor for applying fertilizer, harvesting and marketing a greater amount of produce, and the value of the additional output obtained. In the present case, the task is a little more complex because the change involves the adoption of a technical package (i.e. a combination of practices) rather than a single component of a package, but the same principle applies. Only the aspects of crop production that have changed as a result of the adoption of the technology enter into the calculation of net benefits. The first step in preparing a partial budget therefore is to identify what physical changes in husbandry practices and production levels have occurred as a result of the adoption of improved maize technology.

The physical and financial results of adopting a technical package are time- and location-specific. The additional yield obtained by using fertilizer, for example, varies according to soil type and rainfall. The value of additional production depends on market prices, which vary over time according to supply and demand conditions. Given the agro-climatic diversity of Southern Mali, and the important changes in marketing arrangements that have taken place during the period under study, it is clear that the impact of maize technology adoption in Southern Mali cannot be accurately captured by a single partial budget. On the other hand, attempting to reflect every possible variation in physical and market conditions would require so many partial budgets that the analysis would become unmanageable. The challenge facing the analyst is to identify those factors that have an important effect on the financial outcome of technology adoption and that can be captured in a manageable number of budgets. Furthermore, in order to be able to aggregate farm-level benefits for the region as a whole (a necessary step in the economic analysis undertaken later in this section), the area of maize cultivated under each set of defined agro-climatic and market conditions over time must be known.

In the analysis which follows, an area with more or less similar maize production characteristics is referred to as a "Recommendation Domain," a concept widely used in farming systems research. Each recommendation domain (RD) is represented by one or more partial budgets that correspond to a set of production practices and prices applicable during a specified period of time.

A total of eight RDs have been identified for the farm-level financial analysis, six in the CMDT zone and two in the OHV zone. The criteria used to distinguish RDs include geographical location (northern versus southern parts of the study area), level of crop management (intensive versus semi-intensive), and cropping system (pure stand versus intercropping). Geographical location is an important criterion because the higher average rainfall in the southern part of the study area permits a fuller expression of yield potential. The level of management is an important criterion because maize is responsive to improved husbandry in general, and fertilizer use in particular. The choice of pure stand versus intercropping is relevant not because of any expected difference in total grain yield, but because millet has generally commanded a price premium in rural grain markets since liberalization in 1986. The estimated area of each recommendation domain over the period 1975-90 is provided in table 2, and a summary of their characteristics in table 3.

Table 2. Maize Recommendation Domain Areas (Hectares) in Southern Mali 1975-90

<table>
<tr><th>YEAR</th><th colspan="10">RECOMMENDATION DOMAINS</th></tr>
<tr><th></th><th>CMDT 1</th><th>CMDT 2</th><th>CMDT 3</th><th>CMDT 4</th><th>CMDT 5</th><th>CMDT 6</th><th>TOTAL CMDT</th><th>OHV 1</th><th>OHV 2</th><th>TOTAL OHV</th></tr>
<tr><td>1975</td><td>1099</td><td>1260</td><td colspan="2">1391</td><td colspan="2">1969</td><td>5719</td><td>na</td><td>na</td><td>na</td></tr>
<tr><td>1976</td><td>946</td><td>1414</td><td colspan="2">1018</td><td colspan="2">2129</td><td>5507</td><td>na</td><td>na</td><td>na</td></tr>
<tr><td>1977</td><td>2347</td><td>1194</td><td colspan="2">2014</td><td colspan="2">3397</td><td>8952</td><td>na</td><td>na</td><td>na</td></tr>
<tr><td>1978</td><td>3777</td><td>2847</td><td colspan="2">3522</td><td colspan="2">4323</td><td>14469</td><td>na</td><td>na</td><td>na</td></tr>
<tr><td>1979</td><td>4766</td><td>3678</td><td colspan="2">4997</td><td colspan="2">5535</td><td>18976</td><td>na</td><td>na</td><td>na</td></tr>
<tr><td>1980</td><td>5499</td><td>3973</td><td colspan="2">5014</td><td colspan="2">5633</td><td>20119</td><td>708</td><td>2336</td><td>3044</td></tr>
<tr><td>1981</td><td>6881</td><td>6309</td><td colspan="2">4881</td><td colspan="2">4969</td><td>23040</td><td>956</td><td>3155</td><td>4110</td></tr>
<tr><td>1982</td><td>8575</td><td>7609</td><td colspan="2">6862</td><td colspan="2">5634</td><td>28680</td><td>1204</td><td>3972</td><td>5176</td></tr>
<tr><td>1983</td><td>8891</td><td>8357</td><td colspan="2">8767</td><td colspan="2">4923</td><td>30938</td><td>1276</td><td>4210</td><td>5486</td></tr>
<tr><td>1984</td><td>9835</td><td>10454</td><td colspan="2">12712</td><td colspan="2">4512</td><td>37513</td><td>1281</td><td>4228</td><td>5509</td></tr>
<tr><td>1985</td><td>12908</td><td>11013</td><td colspan="2">17894</td><td colspan="2">6506</td><td>48321</td><td>1303</td><td>4300</td><td>5603</td></tr>
<tr><td>1986</td><td>9401</td><td>14822</td><td>8236</td><td>9720</td><td>4921</td><td>5428</td><td>52528</td><td>1216</td><td>4014</td><td>5230</td></tr>
<tr><td>1987</td><td>9564</td><td>12148</td><td>5956</td><td>10932</td><td>4302</td><td>6943</td><td>49845</td><td>1123</td><td>3705</td><td>4827</td></tr>
<tr><td>1988</td><td>14676</td><td>11568</td><td>9484</td><td>14938</td><td>4337</td><td>5167</td><td>60170</td><td>1167</td><td>3583</td><td>5020</td></tr>
<tr><td>1989</td><td>16942</td><td>13238</td><td>9470</td><td>19211</td><td>4560</td><td>6429</td><td>69849</td><td>1142</td><td>3767</td><td>4909</td></tr>
<tr><td>1990</td><td>17770</td><td>13801</td><td>12559</td><td>19164</td><td>5591</td><td>6624</td><td>75509</td><td>1177</td><td>3886</td><td>5063</td></tr>
</table>

Source: Calculated on the basis of CMDT and OHV annual reports.
Note: For definitions and characteristics of recommendation domains see following page.

Table 3. Definitions and Characteristics of Maize Recommendation Domains (RD) in Southern Mali

CMDT 1	**CMDT North Intensive**: refers to the maize area supervised by the extension service in the Fana and Koutiala regions of CMDT which was plowed, received chemical fertilizer, and possibly organic fertilizer as well.
CMDT 2	**CMDT North Semi-Intensive**: refers to the maize area supervised by the extension service in the Fana and Koutiala regions of CMDT which was plowed and received organic fertilizer only.
CMDT 3	**CMDT South Intensive**: refers to the maize area supervised by the extension service in the Bougouni and Sikasso regions of CMDT which was plowed, received chemical fertilizer, and possibly organic fertilizer as well.
CMDT 4	**CMDT South Intensive (intercropped)**: refers to the maize area supervised by the extension service in the Bougouni and Sikasso regions of CMDT which was plowed, received chemical fertilizer, possibly organic fertilizer as well, and which was intercropped with a long-cycle cereal (usually millet).
CMDT 5	**CMDT South Semi-Intensive**: refers to the maize area supervised by the extension service in the Bougouni and Sikasso regions of CMDT which was plowed and received organic fertilizer only.
CMDT 6	**CMDT South Semi-Intensive (intercropped)**: refers to the maize area supervised by the extension service in the Bougouni and Sikasso regions of CMDT which was plowed and received organic fertilizer only, and which was intercropped with a long-cycle cereal (usually millet).
OHV 1	**OHV Intensive**: refers to the maize area supervised by the extension service in the OHV zone receiving chemical fertilizer.
OHV 2	**OHV Semi-Intensive**: refers to the maize area supervised by the extension service in the OHV zone receiving organic fertilizer.

Different partial budgets are constructed to represent a given RD over time in order to take account of changes in variables that affect profitability, such as a change in fertilizer recommendations or use levels, or changes in input and output prices. For example, maize prices at harvest were lower following cereal price liberalization in 1986 compared to previous years. The specific circumstances of the partial budgets that represent each RD are given in table 4. Only one partial budget is used to represent each of the two OHV zone RDs. A partial budget for the years prior to 1980 is not included because no data are available on either area cultivated or production techniques during this period.

A separate budget for the years after price liberalization is not included since virtually all of the improved maize area is cultivated for the purpose of assuring food self-sufficiency for the producing households rather than for sale, and therefore the removal of the guaranteed price for maize is unlikely to significantly affect their production decisions. Furthermore, refinements to the OHV budgets would have little effect on the aggregate economic return because of the relatively small area of improved maize (less than 15% of the total in most years).

The purpose of each partial budget is to estimate the additional gain to the farm household from the cultivation of maize in a particular RD. This gain, termed incremental net benefit (INB), is measured in CFA per hectare of maize cultivated. The use of terms such as "additional" or "incremental" implies a comparison with some alternative enterprise or technique. What is the appropriate alternative against which improved maize should be compared?

Prior to the promotion of maize as an outer field crop in the mid-1970s, maize was confined to small parcels around the household. These parcels, called "*champs de case*," benefit from very high levels of organic matter that cannot be replicated over a large area. Since expansion of maize on the *champs de case* is not feasible, it would not be valid to compare improved maize production on outer fields with traditional maize production on household plots. The two enterprises are closer to being complements than alternatives.[27] The most widely cultivated cereals on outer fields in Southern Mali are millet and sorghum. For farmers who choose not to—or who are not adequately equipped to—grow maize on their outer fields, these represent the alternative rainfed cereal crops. Since virtually all farmers who grow maize on outer fields are mechanized (the majority with draft animals, a few with small tractors), we compare improved maize to millet or sorghum cultivated on outer fields with the use of animal traction.

5.1.2. Farm-Level Profitability of Improved Maize Production in Southern Mali 1975-90

[27] Many farmers who grow maize on outer fields continue to grow maize on their *champs de case* as well. The latter are sown to early maturing traditional varieties in order to provide fresh maize during the "hungry season," while the outer fields are sown to longer duration improved varieties with higher yield potential for consumption during the dry season and/or for sale.

The technical input/output relations for improved maize production, and the profitability of the enterprise over the last fifteen years, are summarized for each RD in table 4.[28] The top half of the table presents the incremental inputs used and output obtained for maize as compared to millet or sorghum, while the bottom half presents the incremental net benefit (INB) obtained, together with measures of the sensitivity of the INB to changes in the price of maize. We first discuss the technical relationships in more detail and then turn to the financial aspects.

Incremental production and input use: The top row of table 4 presents the estimated yields of maize and the alternative rainfed cereal (millet/sorghum) for each recommendation domain. These yields are based on the opinions of research and extension workers, and yield data published in CMDT and OHV annual reports. Estimated yields of both maize and millet/sorghum are higher for southern RDs (CMDT 3 - 6) than northern RDs (CMDT 1, 2 and OHV 1, 2). Estimated yields of maize are higher for management-intensive RDs (CMDT 1, 3, 4 and OHV 1) than for semi-intensive RDs (CMDT 2, 5, 6 and OHV 2) within the same geographical zone. Millet/sorghum yields are higher for post-1980 budgets reflecting the improvement in crop husbandry as a result of extension efforts for these cereals.

The second row of table 4 presents the additional inputs required to cultivate maize in Southern Mali as opposed to millet/sorghum. The distinction between intensive and semi-intensive RDs is important here. Farmers considered to follow an intensive management regime use chemical fertilizer (and possibly organic fertilizer as well), while farmers considered to follow a semi-intensive regime are entirely dependent on organic fertilizer.[29] The difference is more than one of the source and amount of plant nutrients applied to the crop. In contrast to semi-intensive management, the farmer who chooses an intensive management regime has to make an investment in the crop that requires a cash outflow in an economy where cash is scarce. The application of chemical fertilizer is therefore indicative of a degree of commitment to the crop that will likely be standard of husbandry practices, in order to ensure an acceptable return on the farmer's investment. In all RDs, it is assumed that farmers do not use chemical fertilizer on millet or sorghum.[30]

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[28] The reader should bear in mind that table 3 presents a summary of the financial analysis. Detailed partial budgets for each recommendation domain are presented in the appendix, table 21.

[29] In both cases, plowing is a requirement to qualify as improved.

[30] For both the CMDT and OHV zones, data published in annual reports indicate that chemical fertilizer use on millet and sorghum is negligible, due to the limited yield response with existing varieties.

Table 4. Input/Output Coefficients and Summary Partial Budgets for Improved Maize Compared to Millet/Sorghum in Southern Mali 1975-90

		RECOMMENDATION DOMAIN													
		CMDT 1			CMDT 2		CMDT 3			CMDT4	CMDT 5		CMDT6	OHV 1	OHV 2
PARAMETER	**UNITS**	pre-1980	1980-1986	post-1986	pre-1986	post-1986	pre-1980	1980-1986	post-1986	post-1986	pre-1986	post-1986	post-1986	post-1980	post-1980
INCREMENTAL PRODUCTION															
MAIZE YIELD	KG/HA	1,500	2,000	1,750	1,400	1,500	2,000	2,500	2,250	2,250	1,750	1,750	1,750	1,750	1,500
MILLET/SORGHUM YIELD	KG/HA	800	900	900	900	900	1,000	1,100	1,100	1,100	1,100	1,100	1,100	900	900
INCREMENTAL YIELD	KG/HA	950	1,100	850	600	600	1,250	1,650	1,150	1,150	650	650	650	850	600
INCREMENTAL INPUT USE															
SEED	KG/HA	15	15	15	15	15	15	15	15	15	15	15	15	15	15
SEED DRESSING	KG/HA	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
COMPOUND FERTILIZER (COTTON)	KG/HA	0	100	0	0	0	0	100	0	0	0	0	0	50	0
COMPOUND FERTILIZER (CEREAL)	KG/HA	0	0	50	0	0	0	0	50	50	0	0	0	0	0
UREA FERTILIZER	KG/HA	100	150	75	0	0	100	150	75	75	0	0	0	50	0
INCREMENTAL INCOME															
INCREMENTAL BENEFIT	CFA/HA	31,500	60,500	20,500	27,500	10,500	45,000	77,000	29,500	40,750	35,750	9,500	17,000	46,750	33,000
INCREMENTAL COST	CFA/HA	6,861	27,620	16,976	1,670	1,226	6,861	27,620	16,976	16,976	1,670	1,226	1,226	18,426	1,676
INCREMENTAL NET BENEFIT	CFA/HA	24,639	32,880	3,524	25,830	9,274	38,139	49,380	12,524	23,774	34,080	8,274	15,774	28,324	31,324
NET BENEFIT SENSITIVITY															
MAIZE YIELD OR PRICE +/- 20%	CFA/HA	13,500	22,000	14,000	15,400	12,000	18,000	27,500	18,000	12,000	19,250	14,000	10,000	19,250	16,500
MAIZE YIELD OR PRICE +/- 20%	%INB	55%	67%	397%	60%	129%	47%	56%	144%	50%	57%	169%	63%	79%	53%

Source: Appendix, table 21: Recommendation domain partial budgets (financial).

Notes:

(1) For intercropped recommendation domains (CMDT 4 and CMDT 6) the maize yield includes the yield of the late cereal intercrop (i.e. the figure given represents the combined grain yield).

(2) A maize price of 45 CFA/kg is used prior to 1980, 55 CFA/kg for the period 1980-86, and 40 CFA/kg thereafter (with the exception of the OHV zone where the price is maintained at 55 CFA/KG as virtually all maize is consumed within the farm household).

(3) Changes in output or input prices will result in changes to the incremental net benefit may fall between one partial budget and another, even though physical input/output coefficients have not changed.

Table 4. (cont.) Maize Recommendation Domain (RD) Partial Budgets

CMDT 1 CMDT North Intensive: refers to the supervised maize area in the Fana and Koutiala regions of CMDT which was plowed, received chemical fertilizer, and possibly organic fertilizer as well. This RD is represented by three partial budgets: one for the period before 1980 when only urea fertilizer was recommended by the extension service; one for the period 1980 to 1985 when compound and urea fertilizers were recommended and a guaranteed price of 55 CFA was in effect for maize; and one for the period since 1986 when guaranteed prices have not been available.

CMDT 2 CMDT North Semi-Intensive: refers to the supervised maize area in the Fana and Koutiala regions of CMDT which was plowed and received organic fertilizer only. This RD is represented by two partial budgets: one for the period before 1985 when a guaranteed price of 55 CFA was in effect for maize; and one for the period since 1986 when the guaranteed price has not been available.

CMDT 3 CMDT South Intensive: refers to the supervised maize area in the Bougouni and Sikasso regions of CMDT which was ploughed, received chemical fertilizer, and possibly organic fertilizer as well. This RD is represented by three partial budgets: one for the period before 1980 when only urea fertilizer was recommended by the extension service; one for the period 1980 to 1985 when compound and urea fertilizers were recommended and a guaranteed price of 55 CFA was in effect for maize; and one for the period since 1986 when the guaranteed price has not been available.

CMDT 4 CMDT South Intensive (intercropped): refers to the supervised maize area in the Bougouni and Sikasso regions of CMDT which was plowed, received chemical and possibly organic fertilizer, and which was intercropped with a long-cycle cereal (usually millet). This RD is represented by a single partial budget for the period after 1986 when maize prices were lower than millet. Prior to 1986 the sole and intercropped areas are combined since the total grain yield is similar and the same guaranteed price was available for all coarse grains.

CMDT 5 CMDT South Semi-Intensive: refers to the supervised maize area in the Bougouni and Sikasso regions of CMDT which was ploughed and received organic fertilizer only. This RD is represented by two partial budgets: one for the period before 1985 when a guaranteed price of 55 CFA was in effect for maize; and one for the period since 1986 when the guaranteed price has not been available.

CMDT 6 CMDT South Semi-Intensive (intercropped): refers to the supervised maize area in the Bougouni and Sikasso regions of CMDT which was ploughed and received organic fertilizer only, and which was intercropped with a long-cycle cereal (usually millet). This RD is represented by a single partial budget for the period after 1986 when maize prices were lower than millet. Prior to 1986 the sole and intercropped areas are combined since the total grain yield is similar and the same guaranteed price was available for all coarse grains.

OHV 1 OHV Intensive: refers to the supervised area in the OHV zone receiving chemical fertilizer. This RD is represented by a single partial budget since a high proportion of maize is consumed on the farm, and therefore the value of output to the farm household (opportunity price) has not been significantly affected by the withdrawal of guaranteed prices.

OHV 2 OHV Semi-Intensive: refers to the supervised area in the OHV zone receiving organic fertilizer. This RD is represented by a single partial budget since a high proportion of maize is consumed on the farm, and therefore the value of output to the farm household (opportunity price) has not been significantly affected by the withdrawal of guaranteed prices.

Maize cultivation in intensive RDs is modelled by three partial budgets that represent the evolution of extension recommendations and fertilizer use over time. Prior to 1980, the CMDT recommended only urea top dressing at the rate of 100 kg/ha. This was due to the high fertilizer rate recommended for cotton, designed to ensure that the cereal crop following cotton in the rotation would benefit from residual nutrients. After 1980, the CMDT changed its extension policy from one of allowing cotton to "subsidize" cereal production, to one where each crop was expected to bear its own costs.[31] The reason for this policy change was the increased profitability of maize production following the dramatic cereal price rises of the late 1970s. Recommended fertilizer doses were accordingly reduced for cotton and increased for cereals. For maize, the recommended amount of urea top dressing was raised from 100 kg/ha to 150 kg/ha, and a basal application of 100 kg/ha of compound fertilizer was added. Following the liberalization of cereal prices in 1986, when maize prices fell even more sharply than other cereals, farmers reduced the amounts of fertilizer applied even though recommended doses were unchanged. With the termination of CMDT's specific credit program for maize, many farmers began to divert part of their cotton fertilizer to the maize crop. In the absence of precise data on farmers' fertilizer application rates, we assume farmers currently apply half the recommended dose. Aside from fertilizer, the only additional inputs required are seed and seed dressing to account for the higher seeding rate for maize compared to sorghum.

No incremental labor has been budgeted for maize cultivation. Although maize requires plowing (whereas millet/sorghum is direct seeded) and the harvested ears are harder to thresh, the crop is easier to weed and harvest. The high variability in data on labor inputs for cereal production does not justify the assumption of a significant difference in labor requirement between maize and other cereals cultivated on outer fields. Sensitivity analysis was carried out to assess the effect of a 10 person-day per hectare difference in labor requirements on the profitability of maize production. At between 5,000 CFA and 7,500 CFA per hectare (depending on the opportunity cost of labor in the RD), the effect is small compared to that of variability in the price of maize (discussed below).

Incremental income and sensitivity: The third row of table 4 presents the calculation of incremental net benefit (INB), measured in CFA per hectare of maize cultivated. This is determined by subtracting the incremental cost of maize production from the incremental benefit. The incremental cost of maize production is determined by multiplying the additional inputs used for maize cultivation by their respective financial or opportunity prices. The incremental benefit of maize production is calculated by subtracting the value of millet or sorghum from the value of maize produced (where value is determined by multiplying cereal yields by their respective financial or opportunity prices). Only the results of these calculations are presented in table 4. Detailed calculations for all partial budgets are presented in the appendix (table 21).

[31] Abdoulaye Dolo, Cellule Recherche d'Accompagnement, CMDT. Personal communication.

The most striking result manifested in table 4 is the dramatic fall in the profitability of maize cultivation following the liberalization of cereal prices in 1986.[32] The fall is estimated to be most severe in the sole-cropped intensive management RDs (89% in CMDT 1 and 75% in CMDT 3) and in the sole-cropped semi-intensive southern RD (77% in CMDT 5). The proportionate fall is less severe in the semi-intensive northern RD (64% in CMDT 2). This result is at odds with the reported pattern of expansion of area cultivated to improved maize in recent years. According to the data in table 2, growth has been more rapid in management-intensive RDs (CMDT 1, 3, 4) compared to semi-intensive RDs (CMDT 2, 5, 6). The reasons for this apparent contradiction are not clear.[33] The fall in profitability is estimated to be least severe for the RDs where maize is intercropped (61% in CMDT 4 and 55% in CMDT 6), reflecting the higher price for the late millet intercrop after 1986. This is consistent with the increasing popularity of intercropped versus sole maize (compare CMDT 4 and 3 in table 2).

The vulnerability of incremental net benefits to fluctuations in the price of maize is further illustrated by sensitivity analysis. The bottom row of table 4 indicates the absolute effect on incremental net benefits of a 20% change in maize price (i.e. an increase in the price will increase profits by the amount or percentage shown and a decrease in price will decrease profits by the amount or percentage shown). It is salutary to note that for every sole cropped RD in the CMDT zone today, a drop in maize prices of 20% would result in a loss for the farmer. Only intercropped RDs would avoid loss, testifying to the value of this system as a means of mitigating the risk of price fluctuations.

5.2. Economic Analysis

The internal rate of return (IRR) to investment in the maize research and extension program is estimated at 135%. The incremental net earnings of the program are estimated at CFAF 9,153 million (US$ 37 million). The research and extension program benefits and costs are estimated over a 21 year period, from 1969 to 1990. All benefits and costs are expressed in 1989 constant prices. Because it would be difficult to separate the benefits of research from those of extension, returns are estimated jointly for the research and extension investments.

The principal direct benefits of the maize research and extension program are the increased production it has generated and the increased food security for producers and consumers. In 1988, for example, an estimated 52,000 farm families were growing improved maize in the

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[32] This result is based on a market price of 55 CFA/kg prior to liberalization and 40 CFA/kg afterwards. The post-liberalization price approximates the average price reported by the Système d'Information des Marchés for markets in producing areas during the four months after harvest (October - January). Assuming 50% is consumed in the household and 50% sold, transport costs for marketed produce are offset by avoiding the transport costs of purchased foodgrains.

[33] There are several possible explanations. It is possible that extension workers are inflating the area receiving fertilizer in order to please their superiors. It is also possible that farmers are diverting more fertilizer from the cotton crop to maize in response to food security concerns and relatively stagnant cotton prices during the 1980s.

CMDT zone (CMDT Annual Report). More difficult to quantify is the benefit of enhanced food security. This benefit is partly reflected by the choice of an import parity price to more accurately reflect the value of maize if this commodity has to be purchased on the world market. The direct costs of the program include three components: (1) all the personnel operating expenditures and equipment devoted to maize research in Mali from 1969 to 1990, (2) all the extension expenditures associated with maize technology transfer in the CMDT and OHV areas since 1975, and (3) all incremental costs incurred at farm level in order to adopt the new maize technology. The spillover effects of research undertaken in Mali to other areas of Mali and neighboring countries, as well as any costs of maize research undertaken in other countries or in international research centers, are not accounted for in the economic evaluation.

5.2.1. Assumptions and Methods Used for the Economic Analysis

The incremental net farm benefits estimated in the farm-level financial analysis are converted to economic values: This conversion involves the removal of all transfer payments, such as subsidies or taxes, and the valuation of all items at their opportunity cost or value in use to the society.[34] The use of economic values permits the net effect of the program on national income to be estimated.

The economic values of maize and millet/sorghum are estimated using their economic import parity prices. The justification for considering these two commodities as import substitutes is based on the observation that most maize is consumed in the rural areas during the hungry season (July to October), precisely when maize imports most frequently occur. Import parity prices are calculated on the basis of free-on-board (FOB) commodity prices published by the World Bank (1989 and 1990) and adjusted to 1989 dollars using a 4% inflation rate. The FOB prices are then converted into cost-insurance-and-freight (CIF) values at the shadow exchange rate and adjusted to the relevant points of sale (rural markets) by adding the appropriate economic port charges and delivery costs.[35] The values of these delivery charges are taken from Barry, Salinger, and Stryker (1991). An exchange rate premium of 50% is applied to the traded components of the delivery charges to reflect the overvaluation of the CFA franc with respect to the US dollar. To reflect higher FOB prices for maize during the period 1975-85 compared to the period 1986-90, two series of import parity prices are estimated, each based on the FOB price for the relevant period. To be consistent, the estimation of import parity prices for farm inputs (mainly seeds and fertilizer) follows the same procedure. An FOB price for seed dressing is not available. The economic value of this farm input is calculated by deducting import duties

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[34] In economic analysis, the value in use reflects the purchaser's willingness to pay for a final good or service, while the opportunity cost reflects the benefit foregone by using a scarce resource, either an input or an intermediate good or service, for one purpose instead of for its next best alternative use (Gittinger 1984).

[35] Import parity prices are estimated at the nearest rural market, rather than at farm gate, to reflect the assumption that 50% of cereal production is consumed in the household and 50% sold. As in the farm-level financial analysis, transport costs for marketed produce are offset by transport costs avoided by those families who would otherwise have had to purchase cereals at the market.

from the local 1989 market price and applying the exchange rate premium on the trade component. Details concerning the calculation of the import parity prices for commodities and farm inputs are contained in the appendix (tables 1 to 10).

The economic incremental net farm benefits of adopting the new maize technology are estimated on a per hectare basis for each recommendation domain by replacing the financial prices in the partial farm budgets by their corresponding economic values.

The direct benefit of the maize research and extension program is the aggregate economic incremental net farm benefit stream: This stream is estimated by multiplying the per hectare economic net farm benefits of each recommendation domain by their corresponding areas from 1975 to 1990 (given in table 2). This approach implicitly assumes that producers in the CMDT and OHV areas are "price takers" and face a perfectly elastic demand curve for cereals, given by the international market price.[36] Moreover, the procedure used to estimate the producers surplus also assumes that supply is highly inelastic. This simplifying assumption is correct when fixed inputs such as land and farm labor resources are fully employed, which is observed in the short run but is less evident in the long run. It is reasonable to neglect the stream of net benefits occurring after 1990 because discounting these benefits to 1969 generates negligible values.

The direct costs of maize technology development and transfer include research and extension costs: The maize research program includes two major components—sole maize and maize/cereal intercropping. Each research component can be broken down into on-station and on-farm research and development activities. This distinction is useful as the research costs differ. Tables 22 and 23 give the researcher person-years invested in sole maize research and maize/cereal intercropping research since 1969. To obtain the stream of research costs, an average cost per research person-year is estimated for both on-station research and on-farm research (table 11), based on 1986 and 1987 expenditure figures (ISNAR 1990 and Comité National de la Recherche Agronomique 1988). These average costs per research person-year are converted into economic terms by applying the exchange rate premium to the traded components (table 12). Multiplying these average costs by the number of researcher person-years devoted to on-station and on-farm research and development activities gives the stream of research costs (table 13). The 1969 present value of this stream amounts to CFAF 208 million at a 12% discount rate.

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[36] The procedure used in this economic analysis is the economic-surplus approach which estimates returns to investment by measuring the change in consumer and producer surplus arising from a shift to the right in the supply curve due to technological change. In practice, this approach can be implemented using a benefit-cost analysis, as commonly used by international organizations such as the World Bank or UNIDO. Put simply, benefit-cost analysis of a research and extension program compares the time-valued estimate of the net returns from the innovations generated and transferred by the research and extension program as farmers adopt them, with the time-valued costs of the research and extension program. Similar to the economic surplus approach, it estimates an average rate of return to agricultural research and extension (in contrast to the production function approach, which provides a marginal rate of return by using econometric techniques).

The extension costs are calculated in the same way as the research costs: The economic cost per extension agent-year in the CMDT area is estimated from the 1989 CMDT Contract Plan after removing marketing costs for cotton and transfer payments (taxes and subsidies), subtracting any revenues from marketing cotton and applying the exchange rate premium to the traded components (table 14). Accordingly, the economic cost per extension agent-year in the OHV area is estimated from 1987 to 1989 wages and operating cost figures after applying the exchange rate premium to the traded components. As equipment cost figures are not available for the OHV, they are estimated on the basis of those available for the CMDT (tables 15 and 16). The proportion of extension person-years devoted to the transfer of maize technology is estimated on the basis of the percentage of the total cultivated area in maize, giving a double weight to cotton area[37]. This percentage, estimated for both the CMDT and OHV areas, is then multiplied by the number of extension personnel for each area. Multiplying the economic cost per extension agent-year by the extension person-years devoted to maize for the CMDT and OHV areas gives the stream of extension costs (table 17). The 1969 present value of this stream amounts to CFAF 575 million at a 12% discount rate.

5.2.2. Economic Costs and Benefits of Maize Technology Development and Diffusion

Economic return: Investments in maize research and extension yield a net present value of CFAF 9,153 million (US$ 37 million) at a 12% opportunity cost of capital, and economic internal rate of return (IRR) of 135%. This high IRR is mainly due to the limited research resources devoted to maize (present value CFAF 208 million). With the exception of varietal introduction and tests with different doses of fertilizer, maize technology development and diffusion has mainly been an extension effort (present value CFAF 575 million).[38] A second contributory factor to the high IRR is the use of an import parity price for cereals instead of the market price. Even if maize were to be treated as a non-traded commodity, it would nevertheless have a high value in use since it is mainly consumed during the hungry season when alternative cereals are in scare supply and, therefore, relatively expensive in the local markets.

Sensitivity analysis: The year 1969 was chosen as the starting date of the research cost flow in the base scenario of the economic analysis because of the National Agronomic Research Committee's recommendation to give more emphasis to maize research. However, a limited amount of varietal work complemented with some fertilization trials had been undertaken since 1962. One alternative scenario to the base scenario is to include this research in the research costs flow. As a result, the economic value of the maize research and extension program drops to a present value of CFAF 8,139 million and an internal rate of return of 54%. Such fall in the IRR is mainly due to the longer time lag before obtaining any sizeable increase in maize

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[37] According to interviews with extension management, field agents spend considerably more time on cotton compared to other crops.

[38] The details of the economic evaluation of the maize research and extension program are given in table 18.

production. It shows that a return to investment higher than 54% could have been achieved if the recommendations of the April 1969 Committee to strengthen research on maize had been issued and implemented earlier. It demonstrates the high pay-off to focussing human and financial resources in order to achieve adoption by farmers in a shorter period of time.

The stability of the economic results of the base scenarios (research start dates in 1969 and 1962) is tested with respect to changes in estimates of key parameters included in the analysis. These parameters include the overvaluation of the exchange rate, the inputs of research personnel, the inputs of extension personnel, the area benefitting from maize technology, the maize parity price, and the maize and cereal intercrop yields. Table 5 shows the estimated changes in the economic value of the maize research and extension program as a result of hypothesized unfavorable changes in these parameters for both scenarios. In addition, table 19 presents the economic values resulting from combinations of unfavorable hypotheses.

The estimated exchange rate overvaluation, research, and extension personnel inputs are parameters that least affect the economic value of the maize research program. Dramatic changes in these three parameters affect the economic value of the research and extension program only slightly. The sensitivity tests suggest that errors in estimating these three parameters are unlikely to affect the validity of conclusions drawn from this analysis.

Changes in area benefitting from maize technology moderately affect the economic value of the program. However, increases in the area benefitting from maize technology during the early years of the extension program are particularly important. For example, a doubling of the area benefitting during the period 1975-79 would have increased the IRR from 135 to 163%.

Table 5. Sensitivity Analysis of the Project's Economic Value

	RESEARCH START DATE			
	1969		1962	
PERCENTAGE CHANGE IN THE VARIABLE	NPV AT 12% (1989 mill. C)	IRR (%)	NPV AT 12% (1989 mill. C)	IRR (%)
Base Scenario	9,153	135	8,139	54
Exchange Rate Overvaluation (ERO)				
-25% (implies ERO of 37.5%)	8,465	133	7,525	54
-50% (implies ERO of 25%)	7,777	132	6,912	53
-75% (implies ERO of 12.5%)	7,089	130	6,299	53
-100% (implies ERO of 0%)	6,400	130	5,686	52
Research Personnel Inputs				
+25%	9,101	127	8,084	52
+50%	9,049	120	8,029	50
+75%	8,997	115	7,974	48
+100%	8,945	111	7,919	47
Extension Personnel Inputs				
+25%	9,010	134	8,010	54
+50%	8,866	133	7,882	54
+75%	8,722	132	7,754	53
+100%	8,579	131	7,626	53
Area Benefitting from Maize Technology				
-25%	6,669	123	5,921	51
-50%	4,185	108	3,703	46
-75%	1,701	81	1,485	38
-100% for the 1975-79 period only	11,009	163	9,795	60
Maize Parity Price				
-10%	6,712	123	5,921	51
-20%	4,272	106	3,780	46
-30%	1,831	76	1,601	37
-38%	0	12	0	12
-40%	-610		-579	
-50%	-3,051		-2,758	
-50% for the 1986-90 period only	5,766	135	5,114	54
Maize and Cereal Intercrop Yields				
-10%	6,617	123	5,874	51
-20%	4,080	106	3,609	46
-30%	1,544	76	1,344	37
-36%	0	12	0	12
-40%	-993		-920	
-50%	-3,529		-3,185	

Changes in maize parity price and maize and cereal intercrop yields exert the greatest influence on the economic value of the program. Therefore, changes in these two parameters are carried out in smaller steps. The IRR of the program remains above 12% for a maximum decrease of 38% in the maize parity price or 36% in the maize and cereal intercrop yields.

Any combination of a change of 50% in the exchange rate overvaluation, and 25% in the research and extension personnel inputs, the area benefitting from maize technology, and either the maize parity price or maize and cereal intercrop yields still leads to an acceptable economic value of the maize research and extension program. Only those combinations including unfavorable changes of 25% in both the maize parity price and the maize and cereal intercrop yields result in an IRR below 12%, the opportunity cost of capital.

Conclusions: In economic terms, the maize research and extension program for Southern Mali was highly profitable. This economic profitability is mainly due to the relatively minor costs of research and the rapid adoption of this new technology during the period 1980-86 when farm gate maize price was guaranteed by the Malian cereal marketing board (OPAM).

The rate of return estimated in this study is generally higher than the rates of return found in studies of the benefits of agricultural research in other parts of Africa and the world. The pioneering work of Griliches in 1958 on the introduction of hybrid corn in the United States shows a rate of return between 35% and 40%. A selection of estimates based on the economic-surplus approach as used in this study is reproduced in table 20. Most of these investments achieved rates of return lower than the rate of return estimated in this study. Among these studies, the one most comparable to the Malian maize research program, although much smaller in terms of investment and target group size, is the on-farm research performed on maize in Panama and evaluated by Martinez and Sain (1983). The rate of return to this investment ranges from 188% to 322% depending on the projected technology diffusion.

The rate of return to maize research and extension in Mali estimated in this study is above the rates found in the few evaluations available for African countries. These include the following: the ex-post study by Schwartz et al. (1989) and Schwartz, Sterns, and Oehmke (forthcoming) with a cowpea technology input package in Senegal (63% for the period 1981-87); and the mixed ex-post and ex-ante studies[39] by Monares (1984) with potato seed in Rwanda (40% for the 1978-85 period); a World Bank study (1988) with cotton technology input packages in Burkina Faso, Côte d'Ivoire, and Togo (11% to 41% until 1985, when low cotton prices and exchange rates depressed the rate of return to 5%); and Norgaard (1988) on biological pest control on cassava in Africa (a benefit-cost ratio of 149:1 for the period 1977-2003).

[39] I.e. studies that estimated a rate of return based on a combination of historical and projected future costs and benefits.

6. IMPLICATIONS FOR AGRICULTURAL TECHNOLOGY DEVELOPMENT AND DIFFUSION IN THE FUTURE

Success is invariably gratifying but, as Winston Churchill had cause to reflect during his fruitless efforts to rouse British politicians from complacency following victory in the First World War, it is not always instructive. What can we learn from the experience of maize technology development in Mali? Why did these investments achieve a high rate of return? What are the possibilities for replicating this result? What weaknesses are revealed by this experience that need to be avoided in the future? The time is particularly opportune for IER to address these questions as it embarks on its first strategic plan and simultaneously implements a radical reorganization in support of it. The many stimulating discussions we have been privileged to hold with able and committed Malian researchers and extension staff have convinced us that it would be arrogant of the authors to attempt, in the context of a single short-term study, to answer such important questions on their behalf. The following remarks are therefore partial and addressed more to those outside the Malian National Agricultural Research System who wish to learn from the experience. We begin with the weaknesses, and then proceed to examine the strengths and prospects for replication.

Three main weaknesses of the program have emerged: (1) linkages between research and extension, (2) the lack of economic analysis underpinning technical research findings and extension recommendations, and (3) monitoring of technology adoption. We briefly consider each of these in turn.

During the initial stages of maize technology diffusion, and particularly with the advent of the *Projet Maïs* there was very little interaction between research and extension. With the exception of cotton research, which had been conceived and financed directly in support of cotton development activities, researchers had been passive in regard to the utilization of research results by rural development agencies.[40] The CMDT, on the other hand, was largely autonomous in regard to maize research and development. The *Projet Maïs* undertook parallel research activities at the CMDT seed farms, and was able to test local varietal selections and new husbandry practices through a large program of demonstrations undertaken by extension agents. The myth of this apparent autonomy was shattered by the dramatic outbreak of maize streak virus, which prompted an intense collaborative effort between the CMDT and IER, and within IER between researchers in the fields of entomology, plant pathology, and varietal selection. The lesson has not been forgotten, and the CMDT continues to finance IER's maize research program today.

While relationships between research and extension have clearly improved, the case of maize-millet intercropping research raises some difficult questions. Unlike the case of sole cropped maize, the initiative to improve the traditional system of maize-millet intercropping was taken by research. After on-station researchers had developed an "improved" system (planting maize and millet in separate rows), the package was tested on-farm and concluded to be sound despite

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[40] Dr. Oumar Niangadou. Personal communication.

complaints by farmers that the narrow between-row spacing made mechanical weeding difficult. Subsequently, the CMDT felt obliged to abandon attempts to extend the system for this very reason. Why was no attempt made by researchers to modify the package? How, after the Sikasso-based farming systems team had concluded that chemical fertilizer use was not profitable on maize-millet intercropping after price liberalization in 1986, could the OHV farming system team justify moving directly into pre-extension testing? The existence of communication channels within and between research and extension is necessary but not sufficient for improved effectiveness. The procedures and criteria by which research program proposals and results are evaluated are also critical.

Effective evaluation of technology development requires the integration of economic analysis into the research program, and monitoring of technology adoption in order to provide feedback to research. The decisions by IER and CMDT not to multiply and distribute hybrid seed to farmers on the grounds that it was too costly were taken without any quantitative financial analysis. Similarly, none of the several changes that have been made to maize fertilizer recommendations in the CMDT zone have been subject to financial analysis. The decisions taken are not necessarily wrong, but they are uninformed.

The monitoring of technology adoption by CMDT extension agents does not provide the kind of information that can help focus research. For example, while new maize varietal introductions have been the most dynamic component of the package, no information is collected concerning their levels of adoption in the various agro-climatic zones. The CMDT's monitoring and evaluation unit, which is designed to provide information of a more diagnostic nature to CMDT management, with a staff of 40 enumerators and 5 supervisors in the field, has until recently operated largely in isolation from IER. These weaknesses are also being addressed. The integration of economic analysis and agronomic research is given significant emphasis in IER's strategic plan, and since February 1992 there has been close collaboration between IER economists working on the maize subsector study and the CMDT's monitoring and evaluation unit.

An evaluation of the weaknesses of maize technology development should not be allowed to detract from its accomplishments. The high rate of return to maize research in Mali can be attributed principally to three factors: (1) the low cost of research, (2) the high economic value of the crop, and (3) the rapid rate of technology adoption. We will briefly review what lies behind each of these factors in turn, with particular attention to the issue of replicability in the future.

The low cost of research reflects the limited manpower resources allocated to maize since the inauguration of a cereals crop research program in 1964, under the management of IRAT. The low priority accorded to maize was justified by the small area cultivated relative to millet and sorghum.[41] It was only in 1969 that the decision was taken to give more emphasis to maize on

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[41] The principle of allocating resources between commodities according to their existing economic importance is referred to as the principle of congruity (Norton and Pardey 1987).

the grounds of its potential contribution to increasing food security, and in any case this decision was not backed by any tangible increase in resources for almost a decade. The very limited resources allocated to maize research did not have a negative impact on the promotion of maize starting in the mid-1970s. In formulating recommendations for cultural practices, the CMDT was able to use the results of research undertaken elsewhere in West Africa. An emphasis on making the fullest possible use of research conducted elsewhere in the region will continue to be justified in the future.

The high economic value of maize, measured in terms of an import parity price, reflects the role of increased maize production in substituting for food imports. Throughout the 1970s and early 1980s Mali faced a chronic food deficit situation. Although Mali's aggregate cereal balance improved significantly in the second half of the 1980s, a large proportion of the maize crop continues to be consumed during the hungry season before the longer-cycle millet and sorghum crops are harvested. Informal discussions with cereal traders confirm that maize imports from Côte d'Ivoire during the hungry season are a frequent occurrence. Nevertheless, such a situation will not persist indefinitely in the face of increasing cereal production. Eventually, increased area and improved production techniques will result in cereal surpluses. These surpluses will have a lower economic value than earlier increments in production, either because of the additional delivery costs in the case of export markets, or lower value in use in the case of domestic markets (as livestock feed for example). Thus high historical economic returns to investment in research and extension are not necessarily a guide to the future, which will depend in part on market opportunities.

The high rate of maize technology adoption during the 1980s reflects complementary investments in physical capital, organizational capacity, and incentive policies. In terms of physical capital, high levels of mechanization greatly facilitated the adoption of maize as a field crop. The policy of allowing rural development agencies to purchase grain from farmers at an attractive guaranteed price allowed the CMDT to apply the same integrated approach to maize technology delivery that it had already successfully developed, over the course of many years, for cotton. This approach ensured that all stages in the subsector both prior to production (seed multiplication and distribution, fertilizer and credit delivery, extension advice) and post harvest (purchase and collection, transport, storage, wholesaling) were coordinated through the administrative decisions and technical resources of a single organization.

In the very different policy context of liberalized cereal markets, the coordination of investments over time, and between stages in the overall production process from input manufacture and distribution through to final consumption, has to be achieved through the interaction of a large number of independent decision makers. In seeking to respond to market signals, each of these decision makers faces their own set of resource, information and technological constraints, risks, and transaction costs. In this context, technology adoption at the farm-level production stage for a given commodity will depend on the circumstances facing producers at other stages of a subsector, such as the availability of appropriate equipment for processors, the enforceability of contracts to assure appropriate quality for industrial uses, or the tax structure facing exporters.

In the future, the agricultural research system must be able to assess the needs of a much broader set of clients. Such assessments will bear not only on technological requirements, but also on the needs and opportunities for complementary policy and institutional innovations (Staatz and Bernsten 1992; Boughton and Témé 1992; USAID 1992). This does not mean that the research system must respond to every need identified. In the case of complementary policy and institutional innovations, for example, the emphasis will often be on dialogue with private sector organizations and policymakers. In Mali, IER has responded to this challenge through the inclusion of commodity subsector studies in its strategic research plan. While this is certainly no guarantee of high rates of return to agricultural research investments in the future, it does indicate that IER leadership has economic development as its research goal.

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APPENDIX

Note: In most of the appendix tables, decimal points are indicated by commas, not periods.