Strengthening Sorghum and Pearl Millet Research in Mali

International Crops Research Institute for the Semi-Arid Tropics

Abstract

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The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) began a cooperative research program in 1976 with the principal Malian government agency responsible for agricultural research, the Institut d'économie rurale (IER). The program aimed to establish a strong national infrastructure for long-term research on sorghum and pearl millet and their cropping systems, including both long- and short-term training. The program was established with a 1-year grant from the Ford Foundation, after which funding was assumed by the United States Agency for International Development (USAID).

This report summarizes the activities and achievements of the ICRISAT-Mali program over its 12-year life. Agriculture and agricultural research in Mali are discussed, including the role of agriculture in the Malian economy, resources, constraints to agricultural development, agricultural research institutions, and the context in which the ICRISAT-Mali program was established. The program to strengthen the national agricultural research system is described, including the development of the Cinzana research station and the food technology laboratory at Sotuba, five different types of training, and technical assistance. Breeding and crop improvement work for sorghum and pearl millet are summarized, as is the agronomy and cropping systems research. Accomplishments are summarized and discussed, and recommendations offered to continue the momentum of this highly praised cooperative program. Seven annexes list trainees, consultants, references, and acronyms.

Résumé

Référence : Shetty, S.V.R., Beninati, N.F. et Beckerman, S.R. 1991. Le renforcement des travaux de recherche sur le sorgho et le mil au Mali. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

L'Institut international de recherche sur les cultures des zones tropicales semi-arides (ICRISAT) a mis en place, en 1976, un programme de recherche collaborative avec l'Institut d'économie rurale (IER), l'organisme principal du Gouvernement malien chargé de la recherche agricole. Le programme avait pour but l'établissement d'une infrastructure nationale solide pour les travaux de recherche à long terme sur le sorgho et le mil et leurs systèmes de culture, ainsi que sur la formation à long terme et à court terme. Le programme était crée grâce à une subvention de la Fondation Ford durant 1 an. Par la suite, le financement a été assuré par l'Agence des Etats-Unis pour le développement international (USAID).

Le présent rapport fait le point des activités et des travaux réalisés dans le cadre du programme ICRISAT-Mali au cours de ses 12 ans d'existence. Sont exposés brièvement l'agriculture et la recherche agricole au Mali, ainsi que le rôle de l'agriculture dans l'économie malienne, les ressources, les contraintes au développement agricole, les institutions de recherche agronomique, et le cadre dans lequel a été établi le programme ICRISAT-Mali. Le rapport décrit également le plan de renforcement du programme national de recherche agricole, y compris l'aménagement de la station de recherche à Cinzana et du laboratoire de technologie alimentaire à Sotuba, les cinq différents types de formation et l'assistance technique. Une synthèse des travaux de sélection, d'amélioration du sorgho et du mil, ainsi que de la recherche sur l'agronomie et les systèmes de culture est présentée. Les progrès réalisés par le programme sont analysés, et des recommandations sont faites pour soutenir l'évolution de ce programme coopératif qui a suscité beaucoup d'admiration. Sont dressées en annexe les listes de stagiaires, d'experts-conseils, de références et d'abréviations.

Cover: Achievements and activities of the ICRISAT-Mali Program: Top, the Cinzana Research Station, Mali, with an improved pearl millet in the foreground; bottom, agricultural researchers and administrators in Mali visiting a sorghum-based cropping system trial at Samanko, Mali.

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1991

Portions of the Introduction and Sections 1, 2, 4, and 5 were written by S.V.R. Shetty who also served as the Scientific Editor of the document. N. Beninati wrote the sorghum portion of Section 3. S.R. Beckerman wrote the balance of the report, compiled and edited the document and took the photographs.

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Contents

Foreword

The ICRISAT-Mali program was established in 1976 to assist the national program in developing a strong sorghum and pearl millet research infrastructure, and to conduct long-term research on these two crops and their cropping systems.

This document records notable achievements of this cooperative work on its conclusion in 1991, and we are pleased to note that others have assessed progress favorably:

Extremely cost effective, the Mali model may prove to be one of the most viable approaches in the development of African research and training programs. (Mid-Term Evaluation, 1983.)

The accomplishments are many given the small two-man technical assistance team and reflect the overall success of the project. (Final Evaluation, 1989, prior to continuation.)

Impressed by the success of the program in strengthening national research capacity, particularly in view of the fact that the team consisted of only two scientists. This program has demonstrated the value of a close collaboration between a national and international research organization, supported by long-term funding by a donor. (ICRISAT External Program and External Management Reviews, 1990.)

The achievements of the ICRISAT-Mali program were further endorsed in a letter from the USAID Director in Mali:

ICRISAT has much to be proud of in its 10 years of support to the Malian national program, and the results—both among farmers and researchers—demonstrate the competence and dedication that ICRISAT scientists and administrators have displayed on a continuous basis since the inception of the project. The Malian national research program has been significantly strengthened. My heartfelt congratulations to you and your staff.

But the Institute felt a real sense of collaborative achievement, when, on termination of the project, the Government of Mali felicitated it on the successful implementation of the program to the satisfaction of both the parties. Madame Sy Maimouna Ba, Minister for Rural Development and Environment, conveyed her Government's profound gratitude and commended the project as a model of collaboration between an international agricultural research center and a national agricultural institute.

ICRISAT is grateful to the Government of Mali for the invitation to establish the program, to USAID for major financial support and logistics, and to the Ford Foundation and the Ciba Geigy Research Foundation for additional funding. But major acknowledgment must be made of the commitment to the program by the Government of Mali, and of the helpful ways in which staff of the Institut d'économie rurale (IER) made such productive collaboration possible.

Finally, publication of this document at this juncture is timely because the Consultative Group on International Agricultural Research (the CGIAR) has reaffirmed its objective of support to national agricultural research systems (NARSs) and has encouraged international agricultural research centers (IARCs) to assist NARSs as part of their programs. The CGIAR and IARCs are now considering alternative strategies to foster such partnerships, in which the benefits of strategic research at international level can be made more readily available via this kind of program. We therefore agree with Madame Ba that the experience recorded here may serve as a useful model of one of the ways to achieve this objective. And we commend the report, also, to all readers interested in the development of sorghum and millet research in western Africa.

L.D. Swindale
Director General

Introduction

ICRISAT

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is an international agricultural research center with headquarters in Hyderabad, India. It was created in 1972 as one of the CGIAR centers (Consultative Group on International Agricultural Research), which have as goal to contribute to increasing sustainable food production in developing countries so that the nutritional level and general economic well-being of low-income people are improved.

In 1979, the ICRISAT Sahelian Center (ISC) in Niamey, Niger was created to expand the strategy of combining research with technology exchange based on the concept of centers, teams, and networks. ISC has a long-term commitment to the Sahel, similar to ICRISAT Center's commitment to the semi-arid tropics.

ICRISAT's mandate area is the semi-arid tropics, an area characterized by inadequate and unpredictable rainfall, and large areas of infertile and fragile soils. Within the semi-arid tropics, ICRISAT has a mandate to:

- improve the grain yield and quality of sorghum, millet, chickpea, pigeonpea, and groundnut, and to conserve and disseminate the genetic resources of these crops;
- improve farming systems and stabilize agricultural production through more effective use of natural and human resources in the semi-arid tropics;
- identify constraints to agricultural development and alleviate them through technological changes; and
- ~~work with national and regional research programs to develop and transfer~~ technology to the farmer.

ICRISAT's research teams located in the regional centers and in national programs provide bases for applied research and contribute improved germplasm, components of technologies, and information. These teams also provide the technical core for regional networks and training programs. In addition to western Africa (for sorghum, pearl millet, groundnut, and resource management), the regions that are served by such teams are currently southern Africa (for sorghum, millets, and groundnut), eastern Africa (for sorghum, millets, and pigeonpea), and Latin America (for sorghum).

In addition to ICRISAT Center in India, ISC in Niger, and research teams elsewhere, ICRISAT also supports and participates in many cooperative research and technology transfer networks. These include sorghum and pearl millet networks in western Africa, a sorghum and pearl millet network in Central America, a grain legume network in Asia, and a global cereals network. These networks, along with research teams and Center scientists, assist national scientists and enhance their participation in cooperative research.

The foundation for the concept of centers, teams, and networks was built with the experience acquired by ICRISAT since it began research activities in Africa in 1975. The primary efforts were to improve sorghum and pearl millet. ICRISAT temporarily posted researchers to six African countries: Senegal, Mali, Burkina Faso, Nigeria, Niger, and Sudan with support from multilateral and bilateral donors. Scientists were posted at national research programs to establish close cooperation and reinforce much needed national research infrastructure. The ICRISAT-Mali cooperative program is a bilateral program established in 1976 and placed within the Mali national agricultural research system. While most of ICRISAT's West Africa country programs were later (early to mid-1980s) relocated to establish center (ISC) and regional teams (West Africa Sorghum Improvement Program), the ICRISAT-Mali program continued as a separate entity until 1991.

ICRISAT and IER

The Institut d'économie rurale (IER) is the principal Malian government agency responsible for agricultural research. ICRISAT began a cooperative research program with IER in 1976 with a grant from the Ford Foundation. The ICRISAT-Mali program aimed to establish a strong national infrastructure for long-term research on sorghum and pearl millet and their cropping systems. An ICRISAT breeder/agronomist began to evaluate local sorghums and pearl millet, and introduced some exotic materials. The following year, an agronomist joined the project, and funding was assumed by

USAID/Mali (United States Agency for International Development) under the Opération Mil-Mopti project as a component of the national research program. In 1978, ICRISAT provided funding for a replacement plant breeder.

In 1979, USAID provided ICRISAT with a 3-year, $500 000 grant to continue this work. The purpose of the project, which is now known as Phase I, was to develop a series of technical packages on pearl millet, sorghum, and certain grain legumes for the 400-1200 mm rainfall zone of Mali. Phase I included varietal improvement of sorghum and pearl millet, and agronomic research with emphasis on intercropping, forage production, animal traction, and pigeonpea production.

A review of Phase I in 1980 (Webster) concluded that the project was proceeding as originally planned, and recommended that it be continued. In 1981, USAID provided ICRISAT with a 5-year, $3 750 000 grant to continue its work under Phase II. After a very positive mid-term evaluation (USAID 1983), and because USAID/Mali was emphasizing its role in long-term agricultural development, Phase II was amended for the 4-year period 1986 Jul-1990 Sep with an additional $4 000 000. Final completion of the project is scheduled for 1991 May to allow analysis and reporting of results from the 1990 field season, and for smooth transfer of all project activities to Mali national scientists.

This final report is intended to summarize the activities and achievements of the ICRISAT-Mali project. A brief description of agriculture and agricultural research in Mali is provided, followed by a synthesis of the overall contribution of ICRISAT-Mali to strengthening the national program through contributions to Malian plant breeding and cropping systems research. The project experience is also discussed in terms of recommendations to further improve sorghum- and pearl millet-based cropping systems in West Africa in general, and Mali in particular.

This final report draws on project annual reports, publications by project scientists, and evaluation reports. A list of these and other references is presented in the annexes.

Section 1

Agriculture and Agricultural Research in Mali

Agriculture and Agricultural Research in Mali

Agriculture in the Malian Economy

Much of West Africa lies in a harsh and difficult agroclimatic environment, with fragile soils, diverse crops, and complex production systems. The agricultural resources of Mali vary widely from abundant to marginal, and their exploitation is affected by a host of political, economic, managerial, and environmental factors. As population pressure increases, for many reasons the scope for bringing new land under cultivation will continue to be limited. The production of more food must come from increased yields.

In this context it is useful to examine the role of agriculture in the overall economy of Mali, the resources and constraints to agricultural development, and agricultural research institutions. By examining these broad areas, the stage is set to review the ICRISAT-Mali program.

The performance of the agricultural sector is closely linked to overall economic growth and raising the incomes of poor people. Atwood and Elliott (1989) have described the negative effects that broad economic developments and policy constraints have had on economic performance and income growth in general. Agriculture has been negatively affected by the overall economy, but at the same time, the poor performance of agriculture has worsened; in fact it has been a major cause of negative income trends of low-income people.

Mali's agricultural growth, independent of short-term rainfall variations, remains marginal, even though GDP (gross domestic product) increased due to increased agricultural production during the two exceptionally good rainfall years of 1985/86 and 1986/87. One exception in recent years has been the continued growth of Mali's cotton exports, which has been instrumental in improving overall export growth. In addition, the livestock sector has grown modestly.

The role of agriculture in the economy is crucial: it has contributed an average 48% to GDP over the past 5 years. Seventy-five percent of the population is in rural areas, of which 70% are directly employed in agriculture. The principal cereal crops, sorghum and pearl millet (Fig. 1), account for over 75% of Mali's total cereal production.

On average, agriculture has contributed 70-80% of Mali's foreign exchange earnings over the last 5 years, almost entirely cotton and livestock. Barring any substantial new mineral discoveries, the country's foreign exchange earnings will only rise with an increase in agricultural production. Despite the importance of agriculture in the economy, only 2.3% of the national budget (5.6% before the current debt service crisis) is devoted to agriculture.

Atwood and Elliott (1989) cite three reasons that agriculture's poor performance has been a factor which constrains per capita incomes:

- Agriculture has failed to earn or economize enough on the foreign exchange needed for economic growth. Chronic food deficits require commercial imports that compete for scarce foreign exchange for investment, which slows down the rate of technology development, capital formation, and income growth. During the last 11 years, food deficits have been 155 000 t a^{-1}, of which 96 000 t have been commercially imported at an average annual cost of about $ 29 million, or more than half of the average cotton export value during the same period. As both rice prices and imports rise in the foreseeable future, and world cotton prices stagnate, rice imports are likely to use an even higher portion of foreign exchange generated by cotton exports.
- The inability of agriculture to generate increased rural demand for non-farm goods and services has prevented it from promoting broader economic growth and increasing incomes. Without a progressive rise in the demand from that part of the economy where 70% of the people are employed, overall economic growth prospects must rest largely on urban demand and export markets. In the medium term these are not as promising as they once appeared.
- Agriculture has consistently failed to reduce the cost of rice, which together with pearl millet and sorghum, comprise the key urban wage good. This failure substantially raises the political cost to the government (and reduces its resolve) to undertake the full range of painful measures required to move the Malian economy toward market-oriented economic growth.

Resources

Atwood and Elliott (1989) have summarized the agricultural resources of Mali:

Arable Land

Mali has abundant arable land, much of it located outside the Sahelian zone, where it receives rainfall averaging 600-1000 mm a^{-1}. Between 14 and 20 million ha of the 124 million ha in the country are arable, and in any given season between 10 and 15% are cultivated.

Figure 1. A traditional pearl millet cultivar planted near a village east of Somadougou, near Mopti and Koporo.

In some areas, particularly the southern region, improved technologies have led to increased yields, and the adoption and use of draft animal power is unparalleled elsewhere in West Africa. However, in many areas, yields continue to stagnate, while in other areas land quality is declining due to poor management and soil degradation.

Rangeland and Livestock

Throughout Mali, livestock are of major importance. Lack of inherent fertility and rainfall are the principal determinants of pasture and browse conditions, and thus livestock productivity. Gow (1989) has characterized the dominant pattern of livestock production as extensive, free-roaming, and transhumant herds which exploit the vast grazing lands in the Niger delta from Nov-Apr, and then move south to browse on forest lands, fallow land, and harvested fields.

As crop and livestock activities on the farm become more integrated, forage production and use of crop residues is becoming more important. The role of small ruminants in the various farming systems throughout Mali is also becoming more important. Small ruminants outnumber cattle by two to one, and are a key component in the drive for household self-sufficiency since the money from their sale can be used to buy grain for domestic consumption (Gow 1989).

Livestock contributed 18% of GDP during 1981-85, or approximately 40% of export revenue. Clearly Mali's livestock herd and rangeland are major resources. Estimates of rangeland areas capable of sustained support to large numbers of livestock range from 29 to 44 million ha. Export prospects for Malian animals remain strong for the 1990-94 period, despite some recent problems. Animal traction technology, which has been widely adopted over the last 15 years, will continue to expand during this period. Approximately half of Mali's population rely on livestock as an important income source (Atwood and Elliott 1989).

Water

Despite the major effects of drought and a downward shift in rainfall over the last 20 years, Mali has abundant water resources from its extensive river system, groundwater, and rainfall in the more productive zones.

Estimates of irrigable land vary considerably. The lowest but probably most realistic estimate (UN and World Bank 1985) is 500 000 ha, but only about 180 000 are currently under partial or total water control. Despite abundant water available for irrigation, use of this technology is limited by several problems: management, competition for foreign exchange, high infrastructure costs, and low yields.

It has been estimated that irrigation infrastructure has been added at the rate of approximately 1500 ha a^{-1} for the past 15 years. But for irrigation to expand sufficiently to keep otherwise ballooning food deficits down to even an acceptable level of 226 000 t by the year 2000, at current low yields the inconceivable addition of approximately 20 000 ha of irrigated land every year for the next 12 years would be required.

Natural Resource Problems

In some areas, Mali's rich natural resource base is subject to severe degradation problems from a combination of climatic change and human pressure. This is evidenced by widespread reduction of floating rice, loss of rich perennial grass areas, major permanent shifts of livestock and people to the south, loss of important forest cover, and a host of more localized, less perceptible natural resource problems such as soil erosion.

People

Mali's farmers, despite poverty, a harsh policy environment, and devastating droughts during the last 20 years, have made productive changes in their agricultural activities, ranging from adoption of animal mechanization and new crop varieties to integrating animals and forage production into their farming systems. Mali is among the highest rainfed cotton-yielding countries in the world.

As with other resources, however, a closer examination shows problems:

- It is not easy to adapt new techniques and new crops or varieties to the variable environmental and rainfall situation, both of which have changed considerably during the past 20 years.
- Some of the most poorly endowed farmers, including large numbers of women, have largely been left out of changes in technology, crops, and productivity.
- Despite some efforts to increase literacy, overall literacy and education levels, which have a major effect on farm productivity in developing countries, remain low.
- Many of the most productive rural people, including the better educated, leave farming, not because economic development is drawing them into more productive and rewarding sectors, but rather because agriculture has little to offer them.

Mali's private entrepreneurs, including many rural people, are a major asset. Many of the country's people come from a long tradition of trade and enterprise which remains vibrant despite the policy impediments imposed since independence. These impediments have limited the effectiveness of private entrepreneurs.

Institutions

The agricultural institutions producing or extending technology are also an important resource for Mali. Over the past few years, a number of important rainfed farming technologies have been adopted by farmers thanks to these institutions, including improved maize, sorghum, and cowpea varieties, and animal traction used more widely in Mali than any other West African country. Despite the adoption of some new farming technologies, as in many developing countries, a weak link between research and extension limits technology transfer.

Thanks in part to USAID and other donor activities over the past 10 years, there is a small but growing cadre of competent agricultural researchers now working in Mali. However, there remain important gaps in trained human resources in agriculture, including management training.

New Policy Directions

The last Malian resource considered by Atwood and Elliott is the attitude of Malian policymakers. It is only recently that policymakers began to see farmers, rural people, and private sector actors in rural areas as forming the foundation for agricultural development. The government has now given the highest priority to food self-sufficiency, drought management, and prevention of desertification and other environmental degradation.

Constraints to Agricultural Development

In a manner similar to the mutual influence resources have on one another, a complex interaction of physical, technical, and institutional factors constrains agricultural development in Mali. Atwood and Elliott (1989) identified six categories of constraints to agricultural development:

Production Risk

The key constraint facing Malian farmers is production risk. It is the result of both high rainfall variation and the unpredictable but often widespread impact of biotic stresses. Rainfall variation accounts for as much as 80-90% of variation in food crop production over the past 10 years. Production risk is a constraint not only because in some years there will be inadequate rain, but also because it discourages on-farm investment as well as use of purchased inputs such as fertilizer.

Market Risk

Farmgate prices of most food crops and livestock can vary greatly, partly as a result of production risk, but also partly as a result of an institutional policy environment and a road infrastructure which has discouraged private trader storage and trade within the country. This adds to the disincentives for investment and use of purchased inputs.

Soil Productivity

Soil fertility and structure, as in much of the Sahel, are poor, with fertility characterized by low available phosphorus and nitrogen. In some areas where rural population pressure is heavy, problems of low soil fertility are made worse by shorter fallow periods. In other areas, deforestation has exacerbated the already low fertility. In still other areas, competition among livestock herds, or between herders and farmers in situations of unclear land and resource rights, has led to serious deterioration of soil fertility and structure for both rangeland, cropland,

Figure 2. The tall sorghum and pearl millet in this intercrop are traditional varieties.

and land suitable for reforestation. Soil erosion by wind and rainfall is also common.

Water

Despite its overall abundance, water is also a major constraint. In the past 20 years, rainfall has declined over much of the country. Crops often receive inadequate moisture, even when the overall rainfall is adequate, due to poor soil structure and management practices.

Labor

Labor availability for some groups (women, families with emigrants elsewhere, households with inadequate resources) and some activities (extra weeding, some soil conservation practices) can prevent the level of participation required for the technology or activity in question to make its full contribution to increasing yields.

Government Spending

Government spending for agriculture has been too heavily weighted towards personnel and attempts to manage a broad range of agricultural sector tasks that are better managed by the private sector. Critical services

Figure 3. Harvesting fonio (*Digitaria exilis*), known as "hungry rice" because it is very drought resistant, and the first crop to ripen each year. The stubble is mixed with sand when making bricks.

Figure 4. A pearl millet and cotton rotation.

such as generating basic information and infrastructure that the private sector cannot supply, but which are critical for effective private sector delivery of agricultural services, have been inadequate. Credit and price supports for subsistence crops are negligible.

Malian Rainfed Agriculture

In Mali, sorghum (*Sorghum bicolor*) and pearl millet (*Pennisetum glaucum*) are the basic foods. These two cereal crops are cultivated primarily by subsistence farmers on 1.5 million ha, about 75 percent of the total cultivated land in the country. Although it is not uncommon for sorghum and pearl millet to be grown as sole crops, they are generally grown in association with other crops such as cowpea, maize, groundnut, or vegetables.

Rice is also an important crop in the southern part of the country, while fonio (*Digitaria exilis*) and bambara groundnut (*Vigna subterranea*) are grown quite widely in certain regions. Fonio is often called "hungry rice" because it is the first cereal of the growing season to ripen (Figs. 2-5).

Although sorghum and pearl millet are grown throughout Mali, about 60% of the cultivated area is in the south, which receives more than 800 mm of rain annually, and about 30% in the central, 500-800 mm rainfall area (Fig. 6). In the south, maize, maize/pearl millet, sorghum and pearl millet usually follow cotton and groundnut in the rotation.

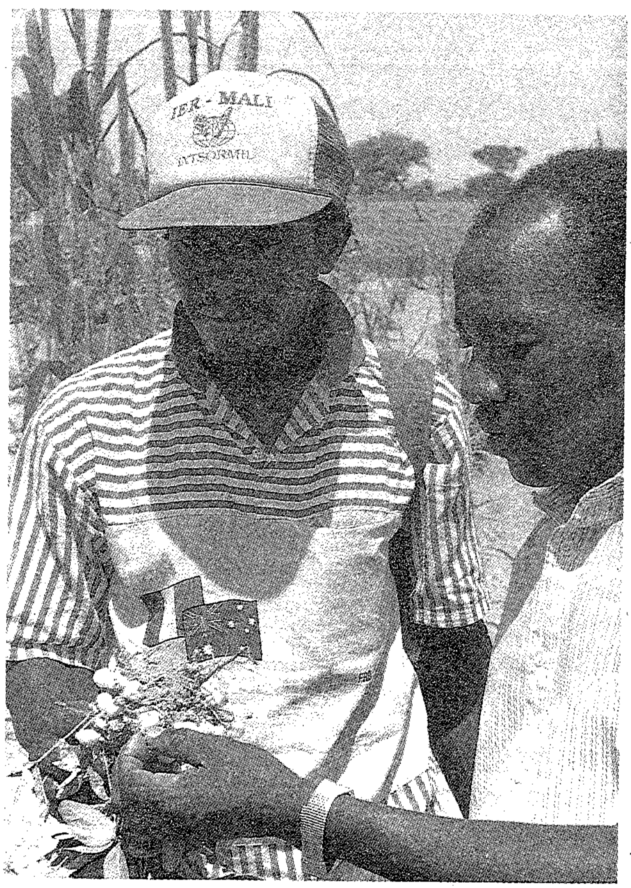


Figure 5. Bambara groundnut (voandzou) produces a low yield compared to *Arachis*, but is more resistant to drought and *Striga*. It is not grown for the oil.

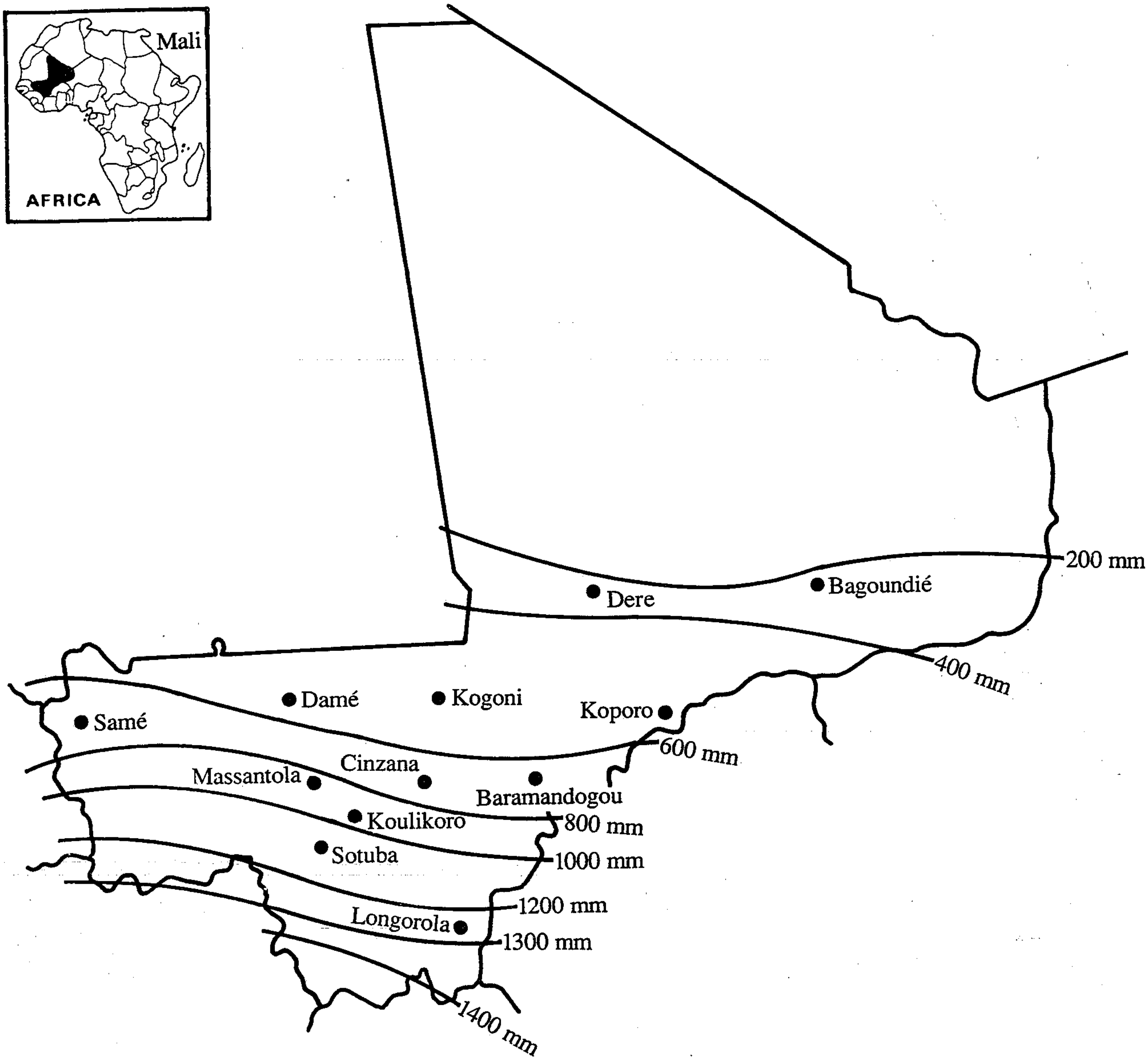


Figure 6. Mean annual rainfall in Mali (Shetty 1989).

The total annual rainfall in Mali varies from 0 mm in the north to 1300 mm in the south. The cropping season lasts up to 5-6 months in the south, beginning in May and lasting until Oct-Nov. As one moves north, the rains begin progressively later and end earlier. The spatial rainfall variation is very high, and effective moisture for plant growth is reduced by high runnoff and evapotranspiration.

Rainfall is highly variable, and technologies which simply increase yield are of limited use during bad rainfall years. Technologies which can mitigate the effects of rainfall variation during bad years often limit yield response under more favorable conditions. Soil moisture is adequate for crop production in many areas thought of as marginal, but soil management techniques which fully utilize available soil moisture are seldom used.

It is interesting to note that during the 17-year period 1968-1984, the annual rainfall has been 18-45% below the long-term average (Table 1). It is estimated that if rainfall isohyets were based on the 1968-1985 rainfall patterns, they would lie 75-90 km south of those based on the long-term averages.

Table 1. Mean annual rainfall (mm) in Mali.

Stations	Mean annual rainfall: Data from various sources	Mean annual rainfall: 17 years (1968–1984)	Decrease during 1968-1984 (%)	Rainfall in 1985
Zone 1				
Sikasso	1373	994	18	1130
Bamako	1088	868	20	907
Kita	1151	867	25	641
Zone 2				
Segou (Cinzana)	724	562	22	566
Zone 3				
Mopti (Koporo)	552	455	18	357
Nioro (Bema)	709	388	45	433
Zone 4				
Timbouctou	225	147	35	–

Source: Shetty 1989.

Added to such rainfall variability, most of the sorghum and pearl millet soils are characterized by relatively low water-holding capacity, low clay content, low organic matter, high erodibility, root-limiting layers, extreme structural instability, low cation-exchange capacity, and a limited ability to supply plant nutrients. These soils are classified as tropical ferruginous soils.

The topography is typically characterized by gentle slopes of weathered ferralitic soils altered by gravelly lateritic outcroppings or escarpments. The soils are generally loamy sand, sandy loam, or sandy, and are classified within the Aerosol group in the north, and as either Luvisols or Alfisols in the Sudanian ecological zone. Spatial variability in these soils is also high. Within a soil type, crop growth frequently varies over relatively short distances, usually associated with differences in physical and chemical properties, including toxicities and nutrient deficiencies.

These soils, with their poor physical and chemical properties, are generally known for their low productivity. Along with highly variable rainfall, the physical resource base for sorghum- and pearl millet-based agriculture in Mali is one of the major factors which limits crop productivity.

Shetty (1989) has characterized the subsistence sorghum- and pearl millet-based cropping systems as not having been changed appreciably by recent innovations in agricultural production techniques. Mixed cropping with cowpea, maize, and groundnut predominates. These cropping patterns are essentially replacement systems in time and space. Food self-sufficiency, labor efficiency, and risk avoidance for farm families are among the principal objectives.

Existing landraces are susceptible to leaf diseases, are drought-prone because of their relatively long growth cycle, and have a moderate yield potential. Sorghum yields are low, about 600 kg ha^{-1}, compared with yield averages of 2000-3000 kg ha^{-1} at nearby experiment stations. Average pearl millet yields range from an estimated 300 kg ha^{-1} in the sandier Sahelian regions to 700 kg ha^{-1} in the higher rainfall areas in the south. Yields of 1500-2000 kg ha^{-1} have been reported in experimental trials.

Technologies for increasing crop yields have been developed, but have not been widely adopted by farmers. Agronomic practices that could increase crop yields and reduce labor costs include: primary tillage with animal traction, timely weed control, row planting, use of animal traction for cultivation and seeding, fungicide and insecticide treatment, high yield potential varieties, higher densities, crop rotations, application of chemical fertilizers and manure, and chemical crop protection.

Experience in West Africa has shown that available technology for increasing sorghum and pearl millet production has not been adopted, primarily because it does not generate the income to buy the associated inputs.

If new strategies include income-generating crops, this will stimulate the use of production inputs on component cereal crops. More productive cropping systems that include income-generating components will encourage the use of management-responsive cultivars.

Agricultural Research Institutions

In order to improve production systems and increase yields in the Sahel, scientific research institutions must have the appropriate physical and human resources. Strong national agricultural research institutions are the key to effective development efforts in West Africa, an area where agriculture is the occupation of most people. In addition to a large staff trained in the diverse fields necessary to increase production, appropriate research facilities are also required.

Until recently, sorghum and pearl millet received limited research attention, usually from expatriate scientists.

Only during the mid-1970s were efforts begun to train Malian researchers who could eventually replace expatriates.

In Mali, three research institutes constitute the national agricultural research system:

- IER (Institut d'économie rurale),
- INRZFH (Institut national de recherche zootechnique, forestière et hydrobiologique), and
- DMA (Division du machinisme agricole).

DMA and IER are within the Ministry of Agriculture, while INRZFH until recently was part of the Ministry of Environment and Livestock. It has now been merged with IER.

Gow (1989) has summarized the history of agricultural research and the agricultural research institutions in Mali:

Agricultural research in Mali began in 1925 under the French colonial administration when a cotton research station was established at M'Pessoba. Until independence in 1960, crop research was conducted at research stations at Kogoni and N'Tarla. In 1927 a *ferme d'élevage* was established at Sotuba, and by 1950 it had been transformed into an experimental livestock research station for the whole of the Sahel (Table 2).

In 1962, the Malian government assumed administrative control of agricultural research with the creation of IER, attached to the Ministry of Agriculture. As a result, there was an increased emphasis on food crops relative to cash crops, but until 1977, crop research was conducted almost entirely under contract by a number of French agricultural research institutes, most notably the Institut de recherches agronomiques tropicales et des cultures vivrières (IRAT).

By the mid-1970s, the research climate had changed. There was now a growing number of qualified Malian researchers, graduates of the Institut polytechnique rural (IPR) at Katibougou, which opened in 1965. Under a new convention signed in 1976, the Malians began to develop their own research agenda. USAID became the major donor for agricultural research in Mali.

Table 2. Historical background of ICRISAT-Mali program.

Year	Agricultural Research Activities
1925	IRCT–cotton research at M'Pessoba
1927	Livestock farm at Sotuba
1950	IRAT–food crops research at Sotuba
1962	IER and IRAT research at Sotuba
1970	IER establishes Division de la recherche agronomique (DRA)
1976	ICRISAT invited by Malian government
1978	Ford Foundation grant–production agronomist
1979	ICRISAT-Mali support grant–cereal breeder added
1983	Mid-term evaluation
1983	Pearl millet breeding transferred to Cinzana
1989	Final evaluation, long-term trainees return
1991	Program conclusion

At the same time, IER began to participate in regional research activities and collaborative research with the International Livestock Centre for Africa (ILCA) for animal husbandry, ICRISAT and the Semi-Arid Food Grain Research and Development Program (SAFGRAD) for rainfed cereals, and West Africa Rice Development Association (WARDA) for rice. Other bilateral donors which began to play important roles include the Canadians in forestry research and the Dutch in soil science, ecology, and farming systems.

In 1981, INRZFH was created to conduct the livestock research previously undertaken by IER, and was placed under the Ministry of Environment and Livestock. During the recent restructuring of IER, INRZFH was again incorporated into IER.

IER is now considered one of the strongest national research institutions in the Sahel, and is the second largest in numbers of personnel and research stations, and its geographical coverage, which includes all the agro-ecological zones in Mali.

IER is responsible for all agricultural research. In collaboration with the respective ministries, it is charged with:

- undertaking technical and socioeconomic studies for agricultural development projects;
- design, management, and execution of agronomic and farming systems research programs;
- planning and evaluation of agricultural development projects; and
- supervision and coordination of all studies and research concerned with agricultural development in Mali.

IER has six divisions under the Director General and Deputy Director General (Fig. 7):

- DAF (Division administrative et financière),
- DDI (Division de la documentation et de l'information),
- DPE (Division de la planification et de l'évaluation),
- DET (Division des études techniques),
- DRA (Division de la recherche agronomique), and
- DRSPR (Division de la recherche sur les systèmes de production rurale).

ICRISAT-Mali is within DRA, which is the core of IER and commands most of its resources, both human and financial. Its 550 employees make up almost 75% of the IER work force. The division is responsible for agronomic research and trials on all crops grown in Mali, and is also responsible for coordinating and controlling agronomic research undertaken in Mali by regional and international organizations.

DRA itself is divided into five sections, four of which deal with cereals and legumes, cotton and fiber, fruit and vegetables, and tobacco and other commercial crops. The fifth section is concerned with seed multiplication, control, and certification of improved varieties and technologies.

ICRISAT-Mali is within the first section, SRCVO (Section de la recherche des cultures vivrières et oléagineuses), at its headquarters at Sotuba, and in addition to trials planted there, also has trials at Cinzana, Samanko, Koporo, N'Tarla, Sikasso, Kita, Bema, Katibougou, and Massantola.

The majority of DRA staff work at Sotuba, the principal research station located just outside Bamako. The balance are located at the regional and subregional research stations managed by the division. The six regional stations and their primary research foci are:

- Cinzana, rainfed crops, particularly cereals and cowpea;
- Mopti, deep-water rice and floating rice;
- Dire, irrigated wheat;
- Kogoni, irrigated rice;
- N'Tarla, cotton, but food crops are receiving increasing attention; and
- Same, cereals and groundnuts.

Each regional station usually has a resident director, four to six professional staff, three to four *moniteurs*, and limited support staff. Since the stations are usually located in or near population centers where housing can be rented, staff are not always provided accommodation on the station. Laboratory and office facilities, however, are part of the station complex.

DRA also manages substations, *points d'appui de recherche* (PARs), which are headed by a resident director, assisted by one or two junior level professionals and two or three *moniteurs*.

During 1990, the Malian government began a major reorganization of agricultural research with the merger of two institutes. In collaboration with International Service for National Agricultural Research (ISNAR), IER is developing long- and medium-term research goals and objectives. The emphasis will be on regionalization and decentralization and encouraging interdisciplinary, problem-oriented research.

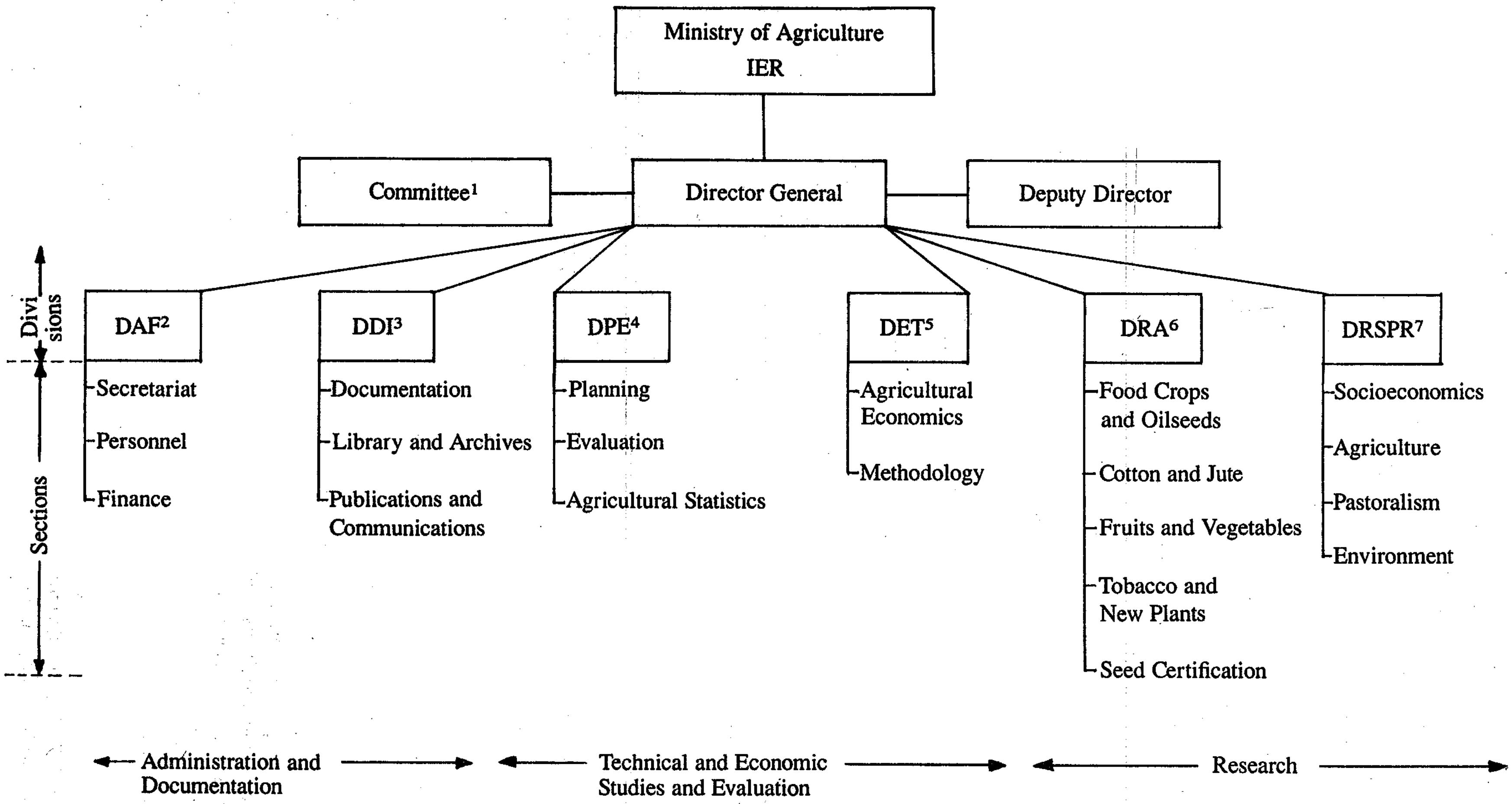
Establishment of ICRISAT-Mali Program

In the mid-1970s, the Malian government set a goal of self-sufficiency in cereals, but recognized that there was virtually no capacity or infrastructure to conduct meaningful research on the two most important cereals, pearl millet and sorghum, and the cropping systems that farmers use to grow them.

It was this recognition that led to the establishment of the ICRISAT-Mali program in 1977 with a 1-year grant from the Ford Foundation, with funding assumed the following year by USAID.

From the earliest days of the program, the broad, overall objectives have remained the same: to strengthen the national program, and to conduct research on crop improvement, agronomy, and cropping systems. Training and developing the infrastructure for research have been two means of strengthening IER. Active participation and collaboration with IER staff on the research planning, execution, and reporting has been an essential element of institutional strengthening.

Within this setting of the agriculture of Mali and the structure of agricultural research, the balance of this report synthesizes the specific activities and major accomplishments of ICRISAT-Mali over the life of the project.



1. Comité scientifique et technique (Comité national de la recherche agronomique).
2. Division administrative et financière.
3. Division de la documentation et de l'information.
4. Division de la planification et de l'évaluation.
5. Division des études techniques.
6. Division de la recherche agronomique.
7. Division de la recherche sur les systèmes de production rurale.

Figure 7. Organization of IER before the current reorganization.

Section 2

Strengthening the National Program

Strengthening the National Program[1]

Infrastructure Development

Like several other countries in West Africa, for many years Mali did not have adequately equipped facilities to conduct food crop research in semi-arid zones. The research infrastructure available at the beginning of the ICRISAT-Mali program was more appropriate to conduct research on cash crops such as cotton and groundnut.

Facilities to support sorghum and pearl millet research, such as screening for biological and physical stresses; soil, crop, and water management research; and conducting cereal quality analyses, were not available at the existing research stations in Mali.

In order to meet these critical needs, several of the existing research structures were provided with the basic requirements for field trials and experimentation, but, at the request of the Director General of IER, the major effort was concentrated on developing a central research station to serve the semi-arid zone of Mali, and creating other facilities such as a cereal technology laboratory and a cold storage for seed.

Cinzana Research Station

The Cinzana Research Station was developed through the joint efforts of IER, ICRISAT-Mali, USAID, and the Ciba-Geigy Foundation (CGF). In addition to technical support from the ICRISAT-Mali program, the Malian government requested that ICRISAT assist them in building a major research station in the semi-arid zone. Station development for national agricultural research programs is not normally a function of research organizations such as ICRISAT, but ICRISAT-Mali was able to help the Malian government obtain funds from USAID and CGF to finance the development and building of the Cinzana station.

The broad research objective of the Cinzana station is to develop and test food crop varieties and cropping systems which contribute to food production in the semi-arid areas of Mali.

The site was selected for its accessibility, soil types, and vegetation and rainfall typical of the zone. The station is located on a slope with five major soil types, ranging from deep sands good for pearl millet, cowpea, and groundnut, to silty heavy soils and hydromorphic clay soils better suited for sorghum production.

During the development phase, a complete soil sampling and analysis were conducted, and samples of the original soils are held in a "soil library" at the station. In the future, studies can be conducted to determine long-term effects of tillage, erosion, or addition of inorganic fertilizers.

A Swiss hydrological team conducted an exhaustive study of the groundwater in the area to locate the most reliable sources of rechargeable water for irrigation. An excellent source was found 7 km from the station. A well was drilled, and along the water line to the station there are nine turn-out valves, which offer the possibility for nine isolated seed multiplication fields.

In 1984, a socioeconomic survey of the area surrounding the station was carried out by Malian agricultural economists under the guidance of an ICRISAT agricultural economist. These data, in addition to describing the prevalent farming systems and helping to define production constraints, will facilitate future impact assessment. In 1986, a follow-up study was conducted in the five villages around the station to analyze the rate of adoption of improved cowpea varieties selected and tested at the station.

The first phase of crop research was to identify stable yielding, early, locally-adapted pearl millet, sorghum, cowpea, and groundnut varieties. The second phase is to tailor these improved varieties in various cropping systems which optimize low inputs and minimize soil degradation. The results from these two phases of research at Cinzana have begun to be tested in farmers' fields. Details of these cropping systems are covered in the section on "Agronomy and Cropping Systems Research" of this report.

A number of research programs funded by various donor agencies conduct research at Cinzana, focusing on different aspects of improving pearl millet- and sorghum-based production systems. Current research activities at Cinzana include:

- breeding pearl millet, sorghum, cowpea, and groundnut;
- improving cereal-legume rotations and pearl millet/groundnut,sorghum/cowpea, and sorghum/groundnut intercropping systems;
- agronomy of improved sorghum and pearl millet cultivars;
- physiology of crop establishment and drought and heat tolerance;

1. Much of the information in this section is from USAID 1989 and Shetty et al. 1989.

- crop protection through screening of pearl millet and sorghum cultivars for insect and disease resistance, including refined screening techniques for downy mildew resistance in pearl millet;
- animal traction equipment adaptation and evaluation;
- soil and water management research;
- soil fertility, soil chemistry, and soil physics research, including evaluation of compost, composting techniques, and manure; and
- management of *Striga* (Fig. 1) and other weeds.

Figure 1. A cowpea *Striga*-resistance trial at the Cinzana research station.

In addition to applied research, the station supplies foundation seed for cowpea, pearl millet, sorghum, and groundnuts to the government seed agency and for on-farm research.

Extensive training, both formal and on-the-job, has been available to Cinzana station personnel. The director of the station, a pearl millet breeder, and his staff are involved in technical exchanges with ICRISAT-Mali, the ICRISAT Sahelian Center in Niamey, and ICRISAT Center in India.

The staff has also had frequent contacts with researchers at American land grant universities and European research institutions working on sorghum and pearl millet. Most of the Cinzana technicians have benefited from ICRISAT in-service training (Annex II), and short courses given by CGF consultants. Many of the long-term trainees (Annex I) also conducted their M.S. or Ph.D. research at Cinzana.

The location of the Cinzana station facilitates interaction and communication with other stations of the Malian

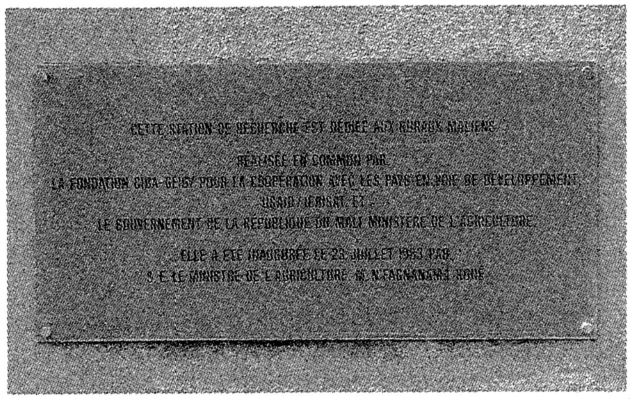


Figure 2. Plaque commemorating the dedication of the Cinzana research station.

national agricultural research program. Sotuba, the center for national food crop research, and the national capital Bamako are only a 3-hour drive to the south on an all-weather road.

The important lower rainfall, semi-arid zone substations of Baramandougou and Koporo-Keniepe are in the major pearl millet- producing areas, located 3-5 h to the northeast of Cinzana. The research station at Sikasso, in southern Mali, is located in the higher rainfall, sorghum-growing subhumid boundary of the semi-arid zone, and is also a 3-hour drive from Cinzana.

The Cinzana station was officially inaugurated in 1983, and has since become the major center of research activity for the semi-arid zone of Mali (Figs 2-6). The station comprises about 280 ha, of which approximately 100 ha have been developed for cultivation. The facilities

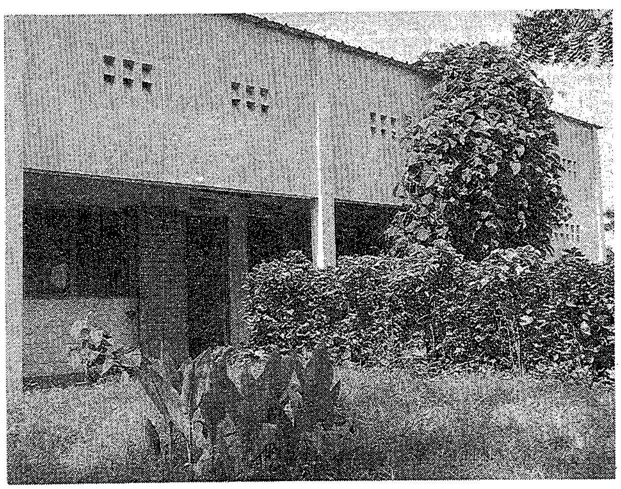


Figure 3. This building houses laboratories and offices at the Cinzana research station.

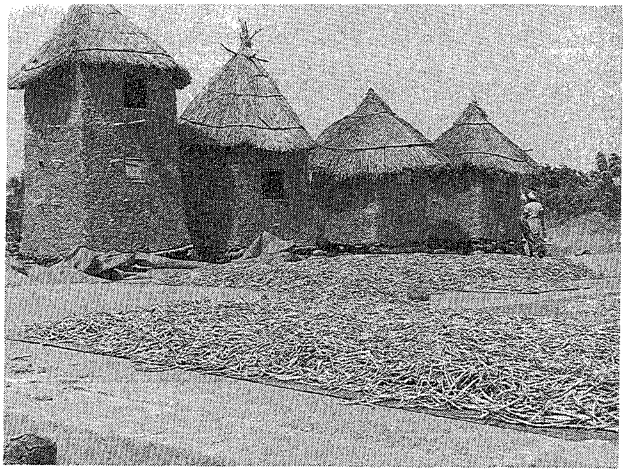


Figure 4. Cowpea drying in the sun at the Cinzana research station in front of traditional grain storage buildings.

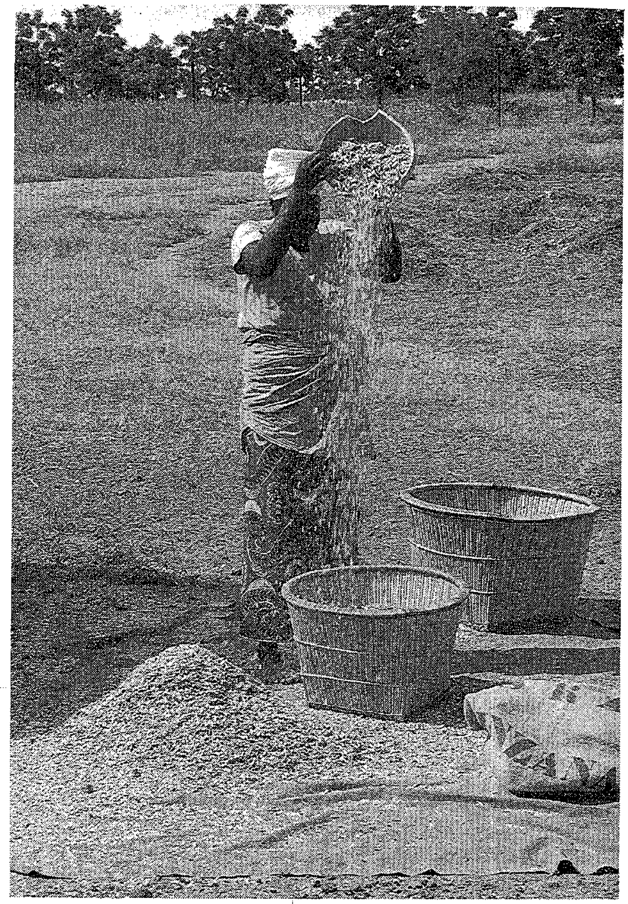


Figure 6. Winnowing cowpea at the Cinzana research station.

include an office building, laboratories, conference room/ library, a guest house with dining facilities, and staff housing.

Additional facilities include equipment and cattle sheds, garages, and storage buildings. A modern workshop for farm equipment and station vehicles has been established, and two diesel generators supply electricity to the offices, laboratories, and housing. Manure for use in cropping systems trials is available from a herd of animals used for animal traction research.

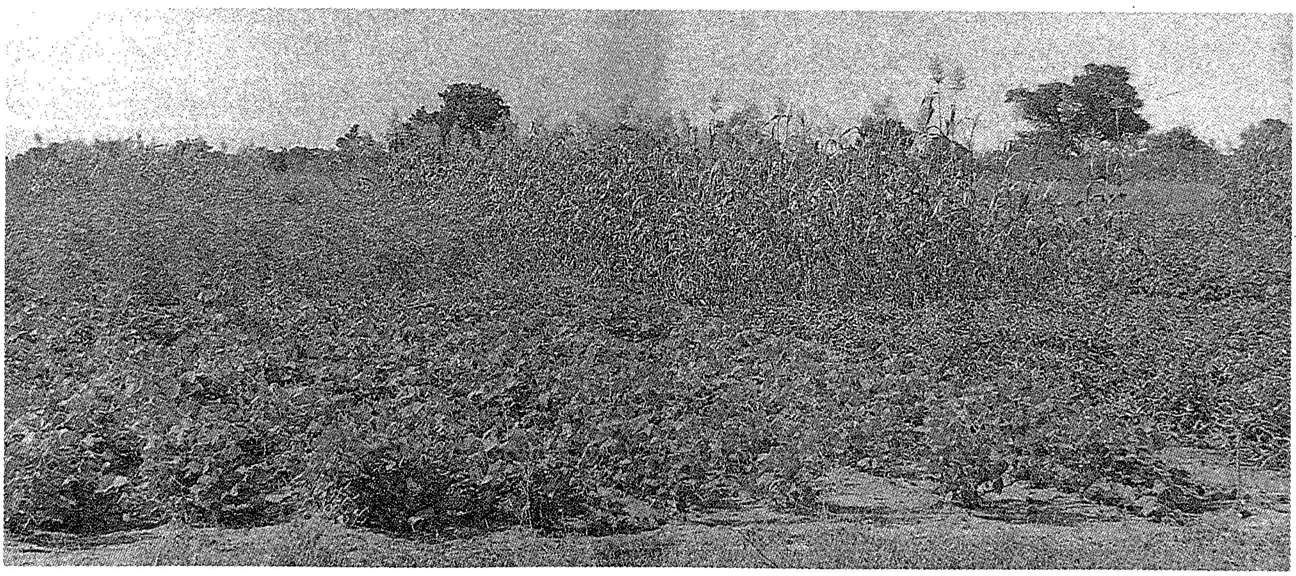


Figure 5. Experimental plots at the Cinzana research station: *Dolichos*, cowpea, *Sesbania*, and sorghum.

The Cinzana station has become a recognized national center for rainfed cropping research, and is considered to be among the best equipped and staffed research stations in West Africa. Many institutions and donor agencies such as the International Sorghum and Pearl Millet Research Project (INTSORMIL),the Soil Management Research Project (TROPSOILS), the Peanut Collaborative Research Support Project (CRSP), the Institut de recherches agronomiques tropicales et des cultures vivrières (IRAT), and Netherlands Cooperation are now supporting research on their mandate crops or systems at the station.

The 1989 final evaluation of the ICRISAT-Mali program (USAID 1989) had high praise for the Cinzana station and its management, and found the station equal in terms of facilities and management to stations in the USA.

Food Technology Laboratory

Cereal quality is an important selection criterion for crop improvement in Mali because the most important staple food, *tô*, is made from sorghum and pearl millet. To ensure the integration of food quality into the breeding program, ICRISAT-Mali established a food quality research capability within IER.

The food technology laboratory was built at Sotuba and initially equipped using ICRISAT-Mali funds. By 1985 it was operating in its own building with trained Malian staff: a Malian food technologist and three technicians. While the proportions vary from year to year, during 1990 the majority of the laboratory operating budget came from INTSORMIL, with IER contributing about 10 percent, and ICRISAT-Mali the balance.

Additional equipment and technical assistance are provided to the food technology laboratory by the USAID-funded INTSORMIL program, which has operated in Mali since the early 1980s.

Two Malian researchers received short-term training at ICRISAT Center in India and at Texas A&M University. A third researcher returned to Mali in late 1987 after completing her M.S. degree in food technology at Texas A&M.

The laboratory is currently conducting research in three areas:

- screening sorghum genetic material from the breeding program for acceptable *tô* quality;
- determining the agronomic factors affecting *tô* quality, such as use of fertilizers, insect damage, disease incidence, and climate; and
- investigating alternative food uses for sorghum and pearl millet such as ready-to-cook, rice-like products, confection foods, composite wheat flour additions, and infant foods.

The food technology laboratory is only able to screen about 200 genotypes each year, which means that only advanced generations can be tested. It would be far more useful and cost effective for the breeding program if the laboratory could screen 500-1000 genotypes each year. If more breeding material could be screened each year, then sorghum and pearl millet cultivars which make poor quality *tô* could be detected in early generations (F_4), and eliminated from the breeding program before the high cost of field testing in advanced stages (Fig. 7). The laboratory is now attracting additional donors to expand the scope of work and screen more genotypes.

The laboratory also supports food quality research on rice, wheat, groundnut, and cowpea. In addition to providing information to breeders on the acceptability of new varieties and breeding materials under development, the food technology program recently began a program to develop alternative food products based on sorghum, pearl millet, maize, groundnut, cowpea, and soybean.

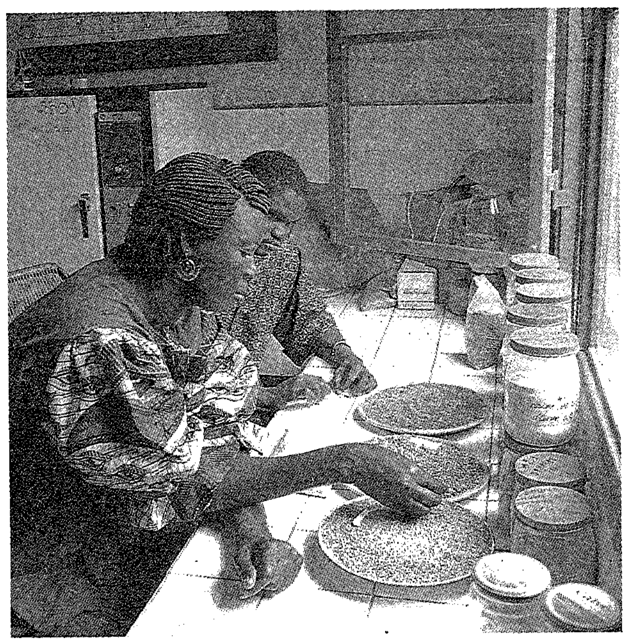


Figure 7. Food scientists at the Sotuba research station determine grain quality during the breeding process.

Other Support

ICRISAT-Mali has been supporting specific activities considered essential to improve production systems because the national agricultural research system is constrained by budgetary limits for operating funds. Examples of such support include:

- operational funds for the Sotuba station, which includes tractor maintenance and repair facilities, fertilizers, chemicals, and farm labor;
- operational support to the Cinzana station, including farm labor, fuel, equipment repair, and maintenance;
- assistance with seed multiplication for on-farm tests of improved cultivars; and
- development of research capacity at other stations in Mali by training equipment operators, field management personnel, and technicians. This training has made multilocational experiments possible without day-to-day supervision by senior staff. Animal traction equipment and training for personnel has facilitated research on cultural techniques at the Koporo-Keniepe, Baramandougou, Kita, and Sikasso stations.

ICRISAT-Mali also funded a seed storage facility at the Sotuba station for locally collected genetic material and breeding material. This cold storage facility, which includes a back-up electrical generator, is used by national scientists working on many crops. Despite the back-up generator, the cold storage facility is not very reliable and therefore needs further improvement.

Training

The development and sustainability of any agricultural research institution hinge on two key factors: the level of human resource development, and the ability of the institution to foster, direct, and sustain meaningful research activities.

All evaluations of the ICRISAT-Mali program have praised the emphasis on staff development. Training efforts have been focused in five areas:

- long-term advanced degree training;
- short-term technical training, emphasizing hands-on research skills in specific areas;
- undergraduate training through advisory roles for certain students at Katibougou Rural Polytechnic Institute (IPR);
- on-the-job training of national research support staff; and
- participation in workshops, conferences, seminars,and tours.

Long-Term Degree Training

The objective of long-term training is to develop the scientific manpower to lead commodity- and discipline-based research. This approach was considered essential in a young institution staffed predominantly with researchers trained only at the undergraduate level.

ICRISAT-Mali provided long-term training opportunities for 11 Malian researchers (Annex I), 8 of whom have now returned, and are contributing significantly to research programs.The training and current roles of some of the students supported by ICRISAT-Mali are:

- The former head of the Division of Agronomic Research returned from the USA in 1986 with a Ph.D. in plant physiology. He is now working closely with ICRISAT-Mali coordinating sorghum and pearl millet improvement programs funded by the national program, ICRISAT-Mali, and INTSORMIL. He also obtained a grant from a USAID program for science and technology cooperation to conduct research on the physiological aspects of heat and drought tolerance of sorghum and pearl millet in Mali.
- The groundnut breeder returned from India in 1986 with an M.S. in breeding, and is now leading the groundnut research program.
- The former Koporo-Keniepe station director returned from the USA in 1986 with an M.S. in soil science, and is now working at the Cinzana station as an agronomist.
- An IER economist returned from the USA in 1987 with an M.S. in agricultural economics, and was associated with the economic analysis of sorghum and pearl millet technologies being developed in Mali. He was one of the principal investigators who conducted socio-economic research in the villages around the Cinzana station. As part of his M.S. research, he studied the adoption of improved cowpea varieties by the farmers around the station. He is now in the U.S. working on his Ph.D.
- A laboratory technologist returned from the USA in 1987 with an M.S. in cereal technology, and is now working with the plant breeders on food quality.
- A research technician returned from the USA in 1981 with a B.S. in agronomy, and after serving as an agronomist at the Cinzana station, is now enrolled in an M.S. program in pearl millet agronomy in the USA.

Short-Term In-Service Training

Short-term training at ICRISAT Center in India,generally referred to as "in-service training", has been a significant component of the ICRISAT-Mali program. Each full-time training session usually lasts 7 months, and is planned to cover a full cropping season. The training is guided by experienced scientific staff.

The trainees live at ICRISAT Center, and an individualized program is developed for each one. They are closely supervised and guided during the training period, and are evaluated at the end of the program. A 2-month intensive English course is provided before the agricultural training begins to enable the trainees to access scientific literature in English, and thus improve communication and interaction with the research community.

To date, 59 middle-level Malian researchers and technicians have participated in this training (Annex II). These trainees form an integral part of the research program in Mali on semi-arid crops and cropping systems. The most recent evaluation (USAID 1989) found exceptional enthusiasm and motivation among the technical staff, due in part to this short-term technical training.

The evaluation team noted that former participants of this program were very good at managing plots, taking observations, and discussing their work with pride: "There is no doubt that the impact of the short-term training program can be seen at all levels of the research process as improving the overall quality of the research results."

There are three main reasons to emphasize in-service training of the type provided at ICRISAT Center:

- The training improves the research skills of the young middle-level research personnel, whose earlier training background has not provided exposure to needed research equipment, tools, techniques, methodologies, and analyses. This is necessary since the educational institutions in Mali, the primary source of undergraduates recruited for entry-level research positions, lack resources, equipment, and modern research facilities.
- Short-term training instills a sense of professionalism and motivation in middle-level researchers. This type of training program also helps to identify motivated researchers with the aptitude for long-term training at the graduate level. Most of the long-term trainees sponsored by ICRISAT-Mali and other agencies had previously completed the short-term training at ICRISAT Center.
- The middle-level researchers develop the skills necessary to exploit the full potential of high-yielding sorghum and pearl millet cultivars which respond to better management. These cultivars are not only being developed in Mali, but are also being introduced from other countries. Such skills are essential for overall crop improvement efforts. Short-term training emphasizes food crop improvement and production agronomy, but in addition, a few researchers train in entomology, plant pathology, agroclimatology, soil and water management, and economics.

In addition to the regular, 7-month, in-service training, some Malian researchers have participated in short-term training on specific topics. Examples in which Malian researchers have participated are a 1-month course on downy mildew research techniques, a 3-month course on agricultural economics research methodology, and a 1-month course on pearl millet improvement research techniques.

It is to the credit of the Malian government and agricultural research institutions that virtually all personnel who have participated in short-term training in India are still employed in responsible positions in agricultural research and development.

Although some of them are not actively engaged in research, they still work within the agricultural ministry or other agencies related to agriculture. Several of these former trainees work with agricultural extension agencies which have taken a particular interest in technologies emerging from sorghum and pearl millet improvement programs.

Undergraduate Thesis Supervision

Using internships for final-year students at the Katibougou Rural Polytechnic Institute (IPR) to conduct meaningful research was an innovative and significant training program offered by the ICRISAT-Mali program. Several of these students have gone on to play vital roles in the development of the Malian agricultural research capacity.

IPR is the educational institution responsible for undergraduate training in agriculture, livestock, and forestry. The graduates of IPR receive B.S.-level training or technician-level diplomas, and are the primary source of entry-level researchers and technicians.

Each student, as a part of his or her degree or diploma requirements, completes a thesis based on a research- or development-related problem . The students spend 5-7 months working on a research topic under the guidance of a qualified researcher (Fig. 8). At the end of the period, the thesis is written using the data collected during the internship, and as a graduation requirement, is defended before a faculty committee.

During 1977-90, ICRISAT-Mali provided 67 internships to IPR undergraduates (Annex III). ICRISAT-Mali scientists and their Malian counterparts served as thesis supervisors, overseeing the work of the interns, and guiding them through the internship period. Most of the thesis subjects related to sorghum and pearl millet improvement, agronomy, and cropping systems.

The internship program also benefited the IPR faculty because of the information exchange, and the exposure to current agronomic research in Mali. Many of these interns have joined IER and ICRISAT-Mali, and some have since participated in short-term and long-term training previously described.

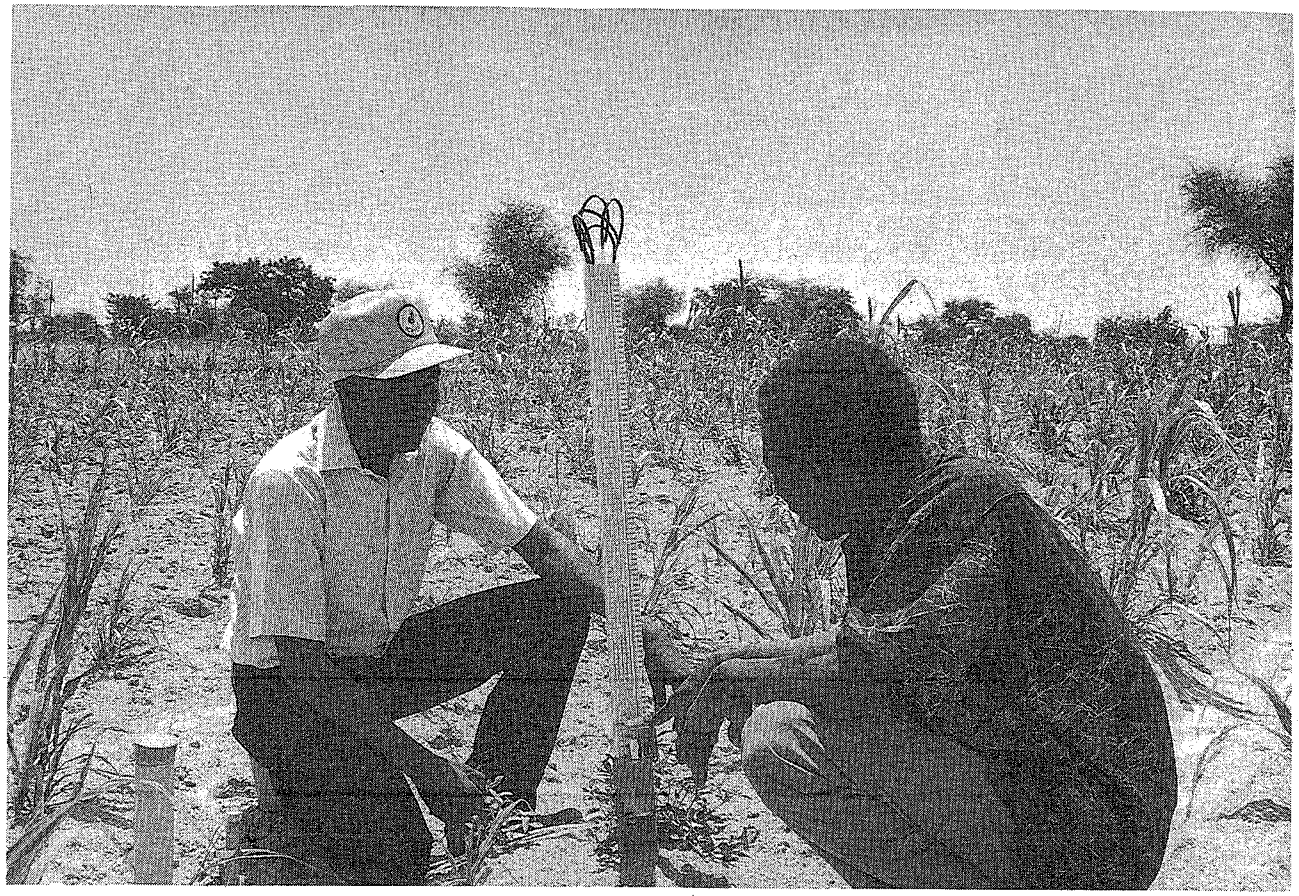


Figure 8. An IPR student examines a tensiometer in his experimental field with an agronomist from Sotuba. The student project studied two genotypes of pearl millet with two levels of added N. Five tensiometers measured soil moisture at depths of 0.45, 0.50, 0.75, 1.80, and 1.90 m.

On-the-Job Training

Training national research support staff on-the-job has been an on-going integral activity of the ICRISAT-Mali program. Two broad types of training were conducted:

- direct contact with the ICRISAT-Mali researchers and their senior national counterparts, and
- instruction from visiting ICRISAT scientists.

Recent examples are sorghum head bug screening techniques, screening for downy mildew resistance in pearl millet, germplasm collection and classification, adaptation and testing of farm equipment, and design of cropping systems experiments.

Other examples of on-the-job training include assisting the national staff with computer analysis, experimental design and interpretation of results, and other specific technical areas such as disease scoring and hybridization techniques.

Probably more important is the long-term professional relationships that are established with counterpart and technical staff, which has instilled a high degree of enthusiasm, and which will remain long after the technical assistance team leaves.

Other training has been offered to mechanics, motorized equipment operators, blacksmiths, and animal traction specialists. Two training programs were organized for animal traction personnel at the National Center for Agricultural Mechanization at Samanko.

Networking

During the last 10 years, over 60 researchers and research managers participated in regional and international conferences, workshops, seminars, and observation tours (Fig. 9). ICRISAT-Mali supported such participation by identifying appropriate events and funding travel for Malian counterparts.

Networking has two purposes: it allows exchange of scientific information among scientists working on simi-

Figure 9. Researchers and guests at a field day stand in front of a traditional, tall sorghum.

lar problems, and it stimulates scientific thought and discussion among researchers.

Several Malian research administrators were encouraged to take study tours to observe agricultural research organizations in other countries. For example, ICRISAT arranged for the Director General of IER and his deputy to visit ICRISAT Center and dryland research centers in India. More recently the Director General of IER visited the research programs at ISC.

Country Workshops

To document the progress in developing improved technologies and to assist in their transfer, joint workshops and field tours for researchers and extension agents were organized. Four major in-country workshops were organized in collaboration with IER and other donor agencies.

Pearl Millet/Maize Cropping Systems

This 1985 workshop at Sikasso provided a forum for researchers and extension agents from southern Mali to synthesize the results of improved pearl millet/maize cropping systems and to develop themes for on-farm evaluation of this system in the cotton zone. As a result, this technology has been adopted by a number of farmers in the CMDT (Compagnie malienne pour le développement des textiles) zone. According to CMDT sources, during 1987 alone, about 20 000 ha of cotton land were cultivated under this improved system.

Intercropping Systems in Mali

Sixty researchers and extension agents discussed 20 papers at this 1987 workshop in Bamako. The participants discussed the progress and problems related to sorghum- and pearl millet-based intercropping in Mali. Research topics which need future investigation, and technologies ready for extension to farmers were identified. Intercropping research techniques and methodologies were standardized. In addition, recommendations for future action by the researchers, development agencies, and administrators were developed. The proceedings of this conference were published, and are in demand not only in Mali, but throughout West Africa (IER and ICRISAT 1987).

Sorghum and Pearl Millet in Mali

Twenty-five papers prepared by both researchers and extension agents were discussed by 75 participants at this 1988 workshop in Bamako. Representatives from donor agencies also attended. The papers summarized sorghum and pearl millet research in Mali, and participants identified future research topics,including technology to improve and stabilize yields. Recommendations for future work were developed. The proceedings of this workshop have also been published (IER and ICRISAT 1988).

Improving Productivity of Malian Soils for Rainfed Cropping Systems

This 1989 workshop was held at the Cinzana station, and was attended by 20 agronomists. The researchers reported on their experimental work with different agronomic factors in several different cropping systems. The participants recommended future strategies to continue research on rainfed cropping systems.

Regional Workshops

ICRISAT-Mali assisted IER in co-hosting two regional workshops in Mali. During 1985, the West African Regional Pearl Millet Workshop was held at the Cinzana station, and in 1986, the West African Regional Sorghum Workshop was held at Bamako. Malian sorghum and pearl millet researchers, along with West African colleagues, presented their work and benefited from intense discussions. Researchers have found the proceedings from these two workshops to be very useful.

Technical Assistance

In the early days of the Malian national research program on sorghum and pearl millet, ICRISAT-Mali provided technical assistance to IER. From its beginning in 1976, the long-term technical assistance has included a production agronomist, and since 1978, a plant breeder.

In addition to coordinating training and activities related to developing a research infrastructure, the team planned and set the research objectives aimed at improving sorghum- and pearl millet-based production systems in Mali.

In addition to long-term technical assistance, short-term consultancies (Fig. 10) were occasionally provided to meet specific needs in such areas as physiology, entomology, pathology, farm power and equipment, soil and water management, soil fertility, statistics, and food technology (Annex IV).

Research conducted by the ICRISAT-Mali team is an integral part of the Malian national program. Planning, execution, and reporting are all conducted jointly with Malian scientists. All annual research plans are subjected to the normal review and approval processes of IER.

As Malian researchers return from degree training, these national scientists are able to assume responsibility for research in several areas. For example, a national breeder now has full responsibility for pearl millet breeding, and the ICRISAT-Mali breeder has concentrated on sorghum.

The technical assistance team has also acted as a catalyst for coordinating research with scientists of other disciplines who are involved with sorghum and pearl millet improvement. Other researchers with INTSORMIL and TROPSOILS have also been involved in planning research strategies and coordinating research activities. The relationship between ICRISAT-Mali and other IER research programs is indicted in Figure 11.

Figure 10. A short-term consultant from ICRISAT Center and Malian researchers discuss experiments at the Cinzana research station.

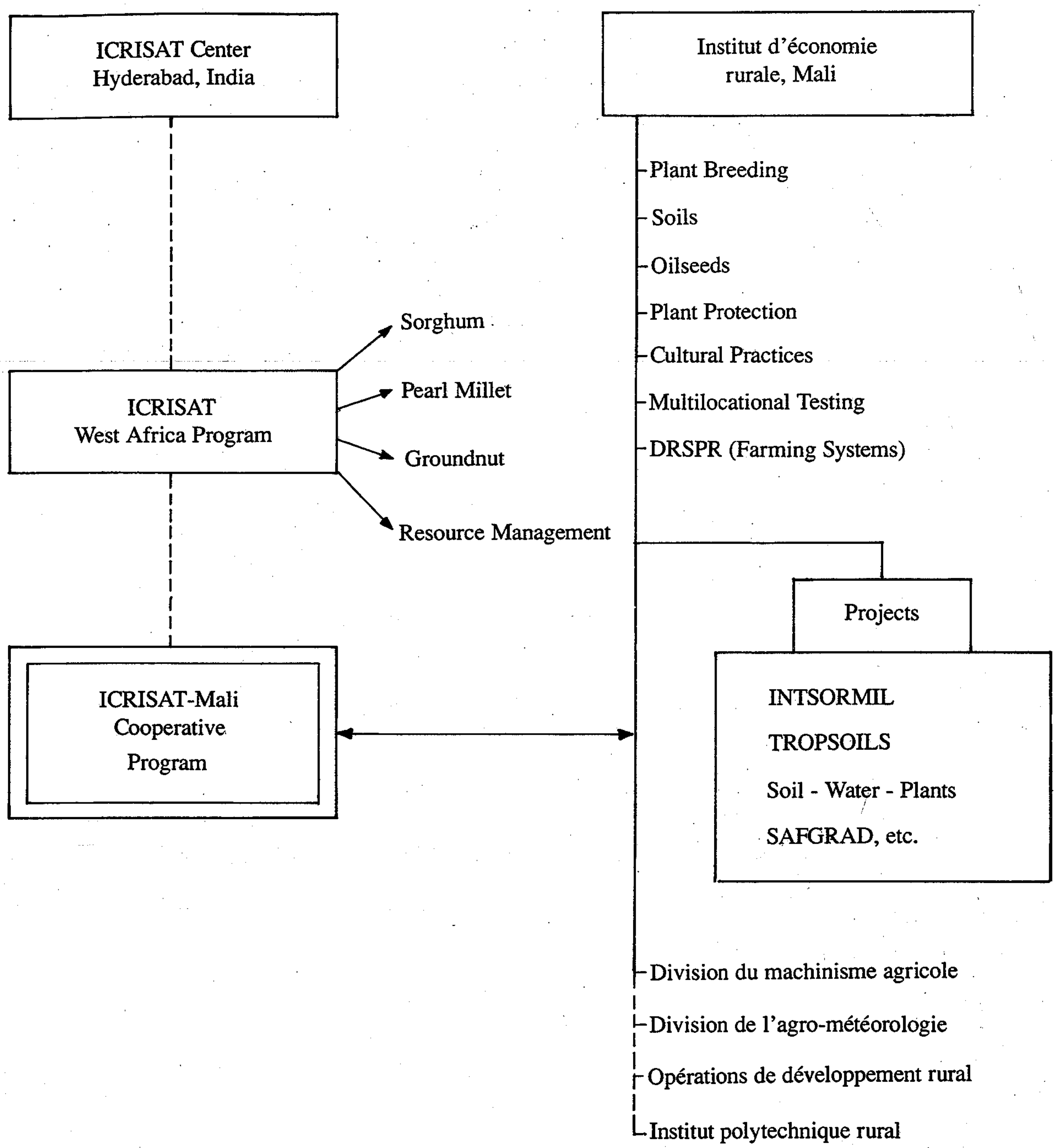


Figure 11. The ICRISAT-Mali cooperative program.

The technical assistance team has been involved in two principal areas of research: breeding high yielding and stable cultivars of sorghum and pearl millet, and design and evaluation of improved cropping systems. These two important areas of research are discussed in great detail in the sections on "Breeding and Crop Improvement" and "Agronomy and Cropping Systems Research" of this report.

Section 3

Breeding and Crop Improvement

Breeding and Crop Improvement

Sorghum

Objectives, Methods, and Priorities

Breeding high-yielding, stable sorghum cultivars which respond to farmer and end-user needs has remained the crop improvement objective since an ICRISAT breeder first came to Mali in 1979. The methods (Table 1) used to achieve this objective have included:

- collection and improvement of Malian landraces,
- introduction of exotic germplasm,
- population breeding,
- modified pedigree selection, and
- limited research on the feasibility of using mutation breeding techniques and breeding F_1 hybrid cultivars.

Table 1. ICRISAT-Mali sorghum breeding chronology.

1979-82	Local collection Develop populations (local × exotic) Develop *tô* screening method Test introductions
1982-86	Mass selection in landraces Population improvement/line derivation
1986	Naming of Malisor-1 through Malisor-7
1986	Pedigree breeding (Malisor × exotic) Population improvement Test new introductions Develop head bug screening On-farm variety tests Improve seed stocks

The proportion of the sorghum breeding effort given to each of these methods has varied from year to year, but now the majority of the breeding lines in advanced yield testing come from the pedigree program, while two main populations are being improved by recurrent selection. Testing of introductions, recently collected local landraces, and hybrids from the ICRISAT WASIP (West African Sorghum Improvement Program) and INTSORMIL programs is limited, but remains an important activity of the program.

In addition to the evolution of the breeding approaches used by the ICRISAT breeders, the diversity of agroecological zones where sorghum cultivation is important (400-1200 mm annual rainfall) has required a stratification of the country. Three principal target zones have different constraints to adoption of sorghum varieties, and as defined below, require different, but overlapping selection criteria (Figs. 1-2).

Even before a plant breeder joined the team, the faults of high-yielding, introduced varieties from non-West African breeding programs highlighted the unique adaptation of the sorghum race guinea to Malian conditions, particularly in the medium and high rainfall areas.

A major constraint, determined early in the breeding program, was the need to make extensive use of local germplasm to overcome the frequent poor quality of the *tô* made from grain of introduced varieties.

As a result, testing breeding material for *tô*-making quality was given major importance as a selection criteria, and led to the eventual development of the IER cereal technology laboratory. Other biotic and abiotic constraints were identified early in the program, and after one season of work in Mali, the second ICRISAT breeder described the strategy for breeding for the three rainfall zones.

Mali was divided into low, medium, and high rainfall zones having long-term average annual rainfalls (the averages are at least 20% less if only the last 15 years are considered) of 400-600 mm, 600-1000 mm, and 1000-2000 mm, respectively. Because the annual rainfall totals are related to the length of the rainy season, the duration of the desired sorghum selections lengthens from the northern, low rainfall zone to the southern, high rainfall zone.

However, depending on the cropping system, date of sowing, and photoperiod response of the genotypes, it should be possible to grow shorter duration materials in a zone further south than the one for which they have been selected.

While it would have been desirable to have a sorghum breeder stationed in each of the zones, trained manpower limitations required prioritization of the objectives for each zone. Breeders concentrated on the objectives that had the highest chance of being attained, and the least chance of getting outside help from ICRISAT or other national programs. Other considerations, such as accessibility and quality of research sites and availability of collaborators within the national program, were also used in determining priorities.

Breeding Approaches for the Rainfall Zones in Mali

Low Rainfall Zone. The approach for the low rainfall zone continues to be observation of introductions, population and pedigree breeding, and yield testing. The principal sites are Cinzana and Bema, with Massantola as a secondary yield-testing site. The principal selection criteria are yield, short duration (<65 d to flowering), drought resistance, emergence in high soil temperature, lodging resistance, and long smut resistance.

Early-maturing, drought-resistant materials bred by ICRISAT Center and other West African programs (notably ICRISAT WASIP), distributed through the SAFGRAD sorghum network, offer a choice of high-yielding varieties and hybrids from which to select. The northern version of the base population, from which inbred lines are generated, is grown during the recombination and selection generations at Cinzana, while both Bema and Cinzana are used as progeny testing sites in the S_2 family testing phase of the recurrent selection scheme.

Biparental crosses targeted for this area are made at Sotuba during the off season, and modified pedigree selection is carried out at Cinzana and Bema. Preliminary yield trials are grown at Bema and Cinzana, and advanced trials containing our selections and the best introduced materials are grown at Bema, Cinzana, and Massantola.

All of the selection criteria mentioned are applied during the course of pedigree selection and progeny test evaluation. Food quality evaluations, including tests of *tô*, are conducted at the cereal quality laboratory at Sotuba. Systematic screening pressure for ability to emerge under high soil temperature is applied to the lines that are included in advanced and preliminary yield trials. This work is carried out in the off-season at Cinzana in collaboration with the plant physiology program.

Intermediate Rainfall Zone. Our primary breeding efforts are concentrated on the intermediate rainfall zone, which encompasses the largest sorghum hectarage, and for which the largest number of research stations and personnel are available. Breeding approaches are the same as for the low rainfall zone, and the principal breeding sites are Cinzana, Sotuba, and Samanko. Additional test sites include Kita, Katibougou, and Koula. The principal selection criteria for this zone are high yield, medium maturity (65-85 d to flowering), acceptable *tô* quality, foliar disease resistance (principally sooty stripe and anthracnose resistance), head bug resistance, drought resistance, and ability to emerge in high soil temperatures.

As with the low rainfall zone, trials from the SAFGRAD network serve as sources of high-yielding lines and hybrids. Similarly, the intermediate version of the

Figure 1. Sorghum breeding plots at the Sotuba research station near Bamako.

base population is improved through recurrent selection with S_2 progeny testing, using Cinzana and either Sotuba or Samanko as the progeny testing sites. The biparental, three-way, and backcross crossing program has increased with crosses made between local varieties, locally bred varieties (such as the Malisor series), and introduced high-yielding varieties. Preliminary yield trials are grown at Cinzana and one of the higher rainfall sites in the zone, either Samanko or Sotuba. Advanced yield trials are grown at three or four sites in this zone, chosen to represent a range of rainfall patterns and latitudes.

The selection procedures for the intermediate zone are similar to those described for the low rainfall zone for those criteria that these two zones have in common. Foliar disease and head bug resistance observations are made in the field, and the head bug resistance of the most promising lines is verified in collaborative trials with the entomology program.

In addition, in 1989 the entomology program, with funding from the ICRISAT-Mali program, INTSORMIL, and SAFGRAD, and technical collaboration with Texas A&M University, started a concentrated research effort on head bug resistance screening techniques for large scale use in the Mali crop improvement program.

High Rainfall Zone. The effort in the high rainfall, southern zone is now limited to testing long-seasoned, photoperiod-sensitive introductions and locally collected land races. The predominant selection criteria are high yield, maturation after normal cessation of the rains, *tô* quality, and foliar disease resistance (including sooty stripe, anthracnose, and gray leaf spot).

With the arrival of the ICRISAT regional program and their emphasis on this zone, the national program will have assistance in resolving some of the more intractable problems, such as screening for mold resistance and increasing the harvest index of late-maturing, photoperiod-sensitive materials.

The photoperiod sensitive population, which underwent a recombination phase in 1987 after it was crossed with a number of higher-yielding, late-maturing introductions, now needs to be subjected to a recurrent selection scheme. This work, as well as the evaluation of introduced materials, should be carried out at Longorola or Tieroula when program staffing permits the placement of a breeder in the zone. When there are sufficient late-

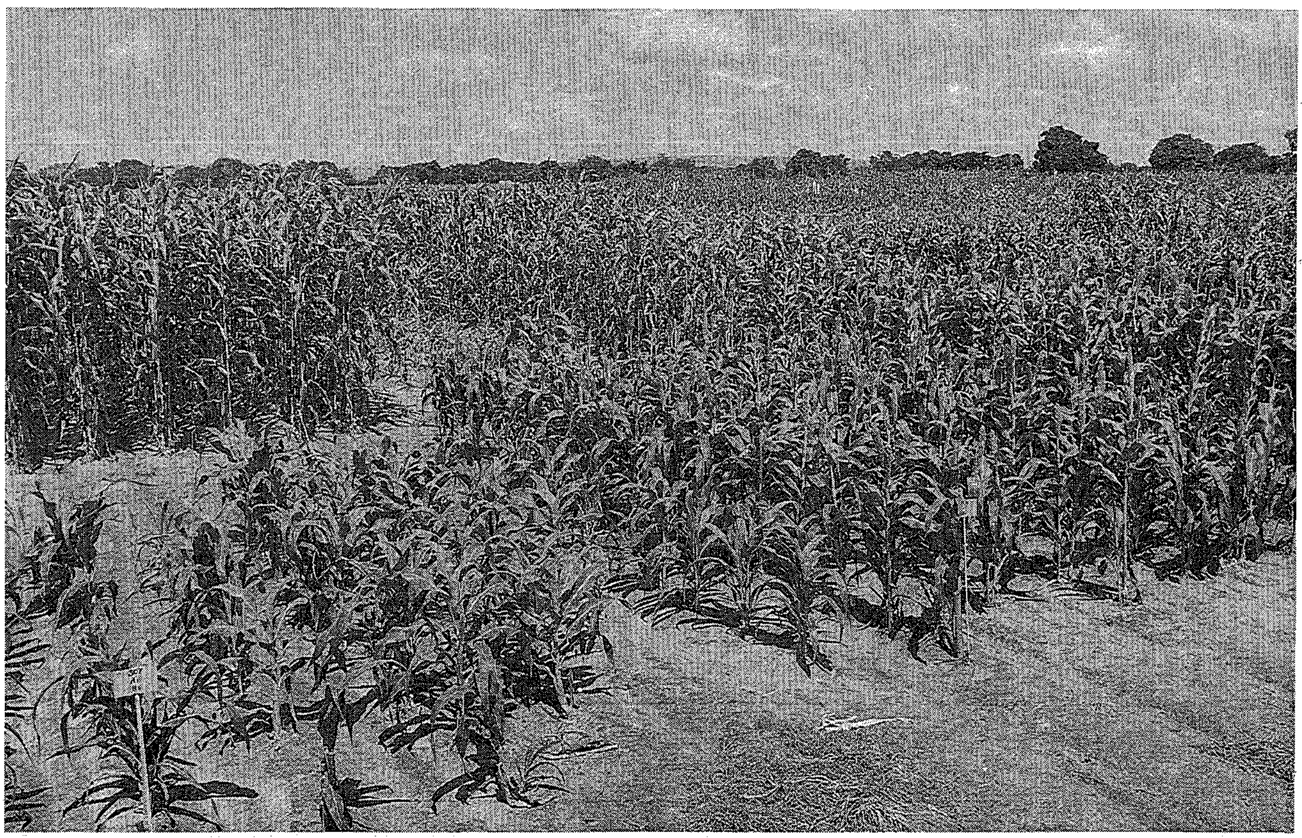


Figure 2. Five varieties of sorghum in a date-of-planting experiment at Sotuba.

Table 2. Yield (t ha^{-1}) of selected landrace varieties chosen from germplasm collected in Mali, 1981-85.

Variety	1981	1982	1983	1984	1985	Mean
CSM-63	1.43[1]		0.46[4]	1.10[5]	1.43[5]	0.94
CSM-219	1.43[1]		0.72[4]	1.22[5]	1.43[7]	1.20
CSM-288	1.06[1]		0.97[4]	0.98[5]	1.03[5]	1.01
CSM-388	1.31[2]	1.71[3]	1.36[2]	0.97[6]	1.72[8]	1.41
CSM-415	2.23[10]	0.75[10]	1.32[11]			1.43
Checks						
Tiemarifing	1.18[2]	1.55[3]	1.43[2]		1.40[9]	1.39
CE-90	1.17[1]		0.62[4]	1.07[5]	1.53[7]	1.10

1. Trial sown at Massantola, Cinzana, Nioro, Same, and Niono.
2. Trial sown at Sotuba, Katibougou, Sikasso, and Kita.
3. Trial sown at Sirakele, Kita, Longorola, and Sotuba.
4. Trial sown at Massantola, Same, and Bema.
5. Trial sown at Cinzana, Massantola, Same, and Bema.
6. Trial sown at Sotuba and Sikasso.
7. Trial sown at Cinzana, Massantola, and Bema.
8. Trial sown at Sotuba, Katibougou, Longorola, Kita, and Koula.
9. Trial sown at Sotuba.
10. Trial sown at Baramandougou, Cinzana, and Massantola.
11. Trial sown at Baramandougou, Cinzana, Massantola, and Katibougou.

Source: Beninati et al. 1988.

maturing materials to be tested, yield trials should also be carried out in this zone.

Selection for all criteria, except *tô* quality, should be applied during the rainy season at Sikasso, where family testing and pedigree selection of population progeny should take place. Grain quality characteristics should be studied by the cereal quality laboratory at Sotuba.

Achievements

The major technical accomplishments (in addition to those of training and infrastructure development) have been the selection of "farmer ready" varieties and the development of a broad germplasm base on which future varietal development should be based.

The "finished" varieties have come from the collection of local landrace cultivars, as direct introductions from other breeding programs, and as derivatives of the ICRISAT-IER program base population. The germplasm base is composed of:

- more than 800 Malian landrace accessions that have been collected, tested, and stored at ICRISAT Center (and to a limited degree in Mali);
- the improved, broad-based Malian base populations; and
- the series of breeding materials ranging from F_1 to F_6 generations from the modified pedigree program initiated in 1987.

Table 3. Malian base population of sorghum.

1979		TP 11 and TP 12 X	
	Hadien Kori |	Sarr |	CE-90 |
1980	F2	F2 X	F2
	Elite hybrids and varieties from ICRISAT Center |	|	|
1981	Full sib crossing to form single population Mass selection and continued introduction of new germplasm		
1987	Started early & medium populations Closed populations and random mated		
1988-90	One cycle S_2 family selection		

In addition, advanced yield trials contain 50 inbred lines–both introductions and populations–several of which could be advanced to the on-farm testing phase in the next two years.

After the germplasm collections made in 1980-81 and 1983, and a preliminary year of evaluation, the most promising lines were grown in yield trials for three years (Table 2). These varieties were retained as the best of the farmers' varieties due to their stable yields over the three years of comparison with other locally grown varieties.

After the creation of the Malian base population (Table 3) using sources of genetic male sterility from Texas A&M (TP11 and TP12), a small, hard-grained Hegari from Senegal (Hadien Kori), and a local Guineense land race (Sarro)–a recurrent selection program was begun in 1981. The method was essentially one of mass selection with frequent crossing of new germplasm onto the population in order to correct for observed faults.

The best of the varieties derived from this population, include Malisor-2 through Malisor-7, and those entries in Tables 4 and 5 having 1985 and 1986 pedigree numbers. Data in Table 4 demonstrate the superior yield performance when compared to the best local variety (CSM 388), of the majority of the population derivatives and the introduced varieties Malisor 84-1, ICSV-1002, and L-30. Sooty stripe and grain mold scores are generally at acceptable levels, but head bug damage ratings, where available, are generally high. It is worth noting that grain mold scores are very site and year dependent, and most varieties will be infected by grain molds if grown in a higher rainfall zone than that for which they have been selected.

By contrast, except for Malisor 84-5, the only lines from the early maturity group showing superior yield to the local check (CSM-219), are the introduced varieties CS-61, ICSV-401, and CE-151 (Table 5). In general, the

Table 4. Agronomic performance of advanced, medium-maturing sorghum breeding lines sown at four locations in Mali, 1986-89.

Variety	Yield (kg ha-1) 1986[1]	1987[2]	1988[3]	1989[4]	Mean	% of CSM 388	Days to 50% flowering	Sooty Stripe[5]	Grain Mold[6]	Head Bugs[7]
85-F4-77	3040	1640	-	1820	2170	123	71	2.5[8]	2.0	7.5
85-F4-205	2470	1830	1080	-	1790	116	74	2.3	3.1	-
85-INT-146	2540	1660	1610	-	1940	126	74	1.3	2.4	-
85-F4-163	-	1730	1630	1610	1660	101	74	3.5[8]	2.0	7.3
85-F4-92	-	1390	1240	-	1315	89	74	1.0	1.9	-
85-F4-189	2540	1560	1460	-	1850	120	75	1.3	2.3	-
85-F4-154	2400	1340	-	-	1870	114	71	-	-	-
85-F4-279	2420	1580	-	-	2000	122	73	-	-	-
85-F4-175	2160	1800	2070	-	2010	131	73	1.0	2.6	-
85-F4-164	-	1910	1320	1890	1710	104	74	2.5[8]	2.0	6.0
Checks										
CSM 388	1660	1620	1350	1990	1655	-	80	2.0	1.0	3.0
MALISOR-84-1	2720	1920	1950	1910	2125	128	66	4.0	3.0	6.3
MALISOR-84-7	2600	1730	1690	1960	2000	121	68	3.0	3.0	3.0
ICSV-1002-BF	2910	2300	1810	-	2340	152	77	2.0	3.1	-
L30	2990	2030	2550	-	2520	164	75	1.0	2.0	-

1. Trial sown at Samanko.
2. Trial sown at Sotuba, Koula, Kita, and Katibougou.
3. Trial sown at Sotuba, Koula, and Kita.
4. Trial sown at Cinzana and Samanko.
5. Sooty stripe: 1 = no infection, 5 = 40% infection. Observations taken at Cinzana in 1989.
6. Grain mold: 1 = no mold, 5 = severely molded. Observations taken at either Samanko in 1988 or Cinzana in 1989.
7. Headbugs: 1 = no attack, 9 = severe attack. Observations taken at Samanko and Cinzana in 1989.
8. Mean of observations made at Samanko and Cinzana in 1989.

Source: IER 1981-90. Rapports des Commissions techniques, Sorghum Breeding, 1987-1990; Rapports des Commissions techniques, Plant Pathology, 1990; Rapports des commissions techniques, Entomology, 1990.

Table 5. Agronomic performance of advanced, early-maturing sorghum breeding lines sown at four locations in Mali, 1986-89.

Variety	Yield (kg ha^{-1}) 1986[1]	1987[2]	1988[2]	1989[2]	Mean	% of CSM 388	Days to 50% flowering	Sooty Stripe[3]	Grey leaf spot[4]	Grain Mold[5]	Head Bugs[6]
85-F4-152	2930	1470	2320	-	2240	98	67	-	2.0	-	7.0
85-F4-43	3010	1170	-	-	2090	98	70	-	-	-	-
85-LO-F6-39	-	1410	2230	2470	2040	100	67	2	2.0	3	6.3
86-F4-161	-	1160	1900	-	1530	77	69	-	1.5	2	7.0
CS-61	-	-	2690	2370	2530	105	66	4	1.5	2	7.7
86-BE-F6-105	-	-	2400	2200	2300	95	66	3	2.8	2	6.3
86-BE-F6-48	-	-	2280	1830	2060	86	64	5	1.8	3	6.3
ICSV-401	-	-	2540	2460	2500	104	66	4	1.0	2	7.7
Checks											
CSM-219	2920	1330	2610	2200	2190		59	-	-	1	-
Malisor-84-5	3120	1380	2800	2440	2440	111	67	3	1.8	2	6.7
Malisor-84-4	2140	870	1610	-	1540	67	60	-	3.3	3	7.3
CSM-63	-	1410	2120	-	1765	90	59	-	3.5	1	3.0
CE-151	3040	1470	2850	2460	2455	112	63	5	2.0	2.5	7.0

1. Trial sown at Cinzana and Bema.
2. Trial sown at Cinzana, Bema, and Massantola.
3. Sooty stripe: 1 = no infection, 5 = 40 % infection. Observations taken at Cinzana in 1989.
4. Grey leaf spot: 1 = no symptoms, 5 = 40 % attack. Observations taken at Cinzana in 1988.
5. Grain mold: 1 = no mold, 5 = severely molded. Observations taken at Cinzana in 1989.
6. Head bugs: 1 = no attack, 5 = severe attack. Observations taken at Cinzana, Bema, and Massantola.

Source: IER 1981-90. Rapports des Commissions techniques, Sorghum Breeding, 1987-1990; Rapports des Commissions techniques, Plant Pathology, 1989 and 1990; Rapports des commissions techniques, Entomology, 1990.

disease ratings of these varieties are within tolerable limits, and although head bug damage ratings are high, head bug infestations are normally of minor importance in the zone of adaptation of these varieties.

As mentioned above, selection of breeding lines having acceptable *tô*-making quality has been a priority of the program since its inception. All the materials which the breeder received in the breeding program in 1979 made unacceptable *tô*. The vitrosity scores of the introduced varieties ICSV 1001-BF and Malisor 84-1 demonstrate that even if they are well-adapted agronomically, grain quality can be a problem (Table 6).

The stability values for the same two varieties show that poor vitrosity does not necessarily translate into poor *tô*-keeping ability nor low recovery rates. However, the high quality that can be obtained through maintaining selection pressure for good grain quality is demonstrated by Malisor-7, which is nearly as good as the consistent local variety CSM-388. A similar pattern of lower quality grain produced by introduced varieties (CE-151), when compared to Mali population derivatives (Malisor 84-5)

Table 6. Quality characteristics of representative medium-maturity Malian sorghum varieties.

	Vitrosity[1] Mean	SD	Recovery[2] Mean	SD	Stability[3] Mean	SD
Malisor 84-7	2.4	.65	79	16	1.3	0.69
Malisor 84-1	3.4	.77	85	11	1.8	0.86
CSM-388	2.1	.72	89	9	1.5	0.47
ICSV 1002-BF	3.7	.52	80	12	2.4	1.2

1. Vitrosity: Scored from 1 = most vitreous to 5 = most floury. Mean from nine trials grown in 1985-88.
2. Recovery: Dried, decorticated product recovered as a percent of total undecorticated grain. Mean from eight trials grown in 1985, 1986, and 1988.
3. Stability: Scored from 1 = very firm to 5 = very soft. Mean from eight trials grown in 1985, 1986, and 1988.

Source: IER 1981-90. Rapports des commissions techniques, Quality Lab, 1986-1989.

and locals (CSM-219), was demonstrated for early-maturing varieties (Table 7).

Since 1985 the susceptibility of improved genotypes to damage from head bug infestation has been the object of a joint research effort of breeders from ICRISAT-Mali and IER, and entomologists from the national program, ICRISAT Center, and recently, INTSORMIL.

Malisor 84-7 has demonstrated a good tolerance to head bug infestation (Table 8). In addition to consistently low damage ratings when compared to other genotypes being tested in West Africa, the low population build up on the variety appears to demonstrate a non-preference for the variety. As a result of earlier observations on this tolerance and the generally high-quality grain of Malisor 84-7, it has been and continues to be widely used in crossing programs in the region. The first progeny from crosses using Malisor 84-7 as a parent in our program reached the preliminary yield trial stage in 1990.

In response to recent recognition that the best of the selected varieties from the program were not being grown by farmers, we began research-managed, on-farm trials in 1989, and have continued in 1990. In an attempt to better understand the relatively low yields of our improved varieties relative to local guinea varieties when sown in trials in farmers' fields by the national multilocational trial agronomists, we conducted trials in 1988 in four farmers' fields near the Cinzana research station. All cultural practices were those normally used by the farmers except for the use of inorganic fertilizers at rates recommended by the extension service. All operations were carried out by the farmer under the supervision of our technician.

Table 9 shows yield and plant density data for the three sites harvested. A significant (P>0.05) variety x farm interaction existed for both variables and prevents firm conclusion about overall varietal performance. However, it appears that the relative poor mean yield of Malisor 84-7, when compared to the guinea variety CSM-219, is due to the low plant stand at Farms 2 and 3. Similarly, yields of Malisor 84-5 appear to be adversely affected by the low number of harvested hills. By contrast, Malisor 84-1, which had a near or above average number of hills at each site, showed the greatest yield potential, even under farmer management.

Table 7. Quality characteristics of representative early maturing Malian sorghum lines.

	Vitrosity[1]		Recovery[2]		Stability[3]	
	Mean	SD	Mean	SD	Mean	SD
Malisor 84-5	2.7	.40	70	10	2.2	1.1
CSM-219	3.2	.20	71	7	1.6	1.0
CE-151	3.8	.57	66	10	2.3	0.7

1. Vitrosity: Scored from 1 = most vitreous to 5 = most floury. Mean from three trials grown in 1986-87.
2. Recovery: Dried, decorticated product recovered as a percent of total undecorticated grain. Mean from five trials grown in 1986 and 1988.
3. Stability: Scored from 1 = very firm to 5 = very soft. Mean from five trials grown in 1986 and 1988.

Source: IER 1981-90. Rapports des commissions techniques, Quality Lab, 1986-1989.

Table 8. Head bug (*Eurystylus* spp) number and damage rating for Malisor-7 compared with 109 other genotypes from 4 trials and 3 locations in Mali in 1989.

	Infestation[1] (number of bugs/5 panicles)[3]				Damage rating[1,2,4]		
	Cinzana	Farako Ba	Samanko 1	Samanko 2	Farako Ba	Samanko 3	Samanko 4
Malisor-7	1.8	5.7	6.6	4.8	3.3	3.0	4.0
Trial mean	6.6	12.3	18.5	17.8	5.3	5.9	5.4
SE	2.7	1.1	5.1	3.8	0.9	1.0	0.9
No. of entries	12	12	12	18	12	25	64

1. Cinzana, Farako Ba, and Samanko 1 data from ICRISAT WASIP Advanced Head Bug Nursery, Samanko 2 from ICRISAT Center International Sorghum Head Bug Nursery.
2. Samanko 3 data from ICRISAT-IER Advanced Yield Trial, Samanko 4 data from ICRISAT-IER Preliminary Yield Trial.
3. Number of head bugs per five panicles per plot under natural infestation sampled at milk stage.
4. Damage rating: 1 = grain with a few feeding punctures to 9 = grain showing more than 75% shriveling.

Source: Sharma 1989 (Personal Communication).

Table 9. Performance of sorghum varieties in 1989 on-farm trials near Cinzana, Mali.[1]

	Farm 1		Farm 2		Farm 3		Mean	
Entry	Yield ($t\ ha^{-1}$)	Hills harvested	Yield ($t\ ha^{-1}$)	Hills harvested	Yield ($t\ ha^{-1}$)	Hills harvested	Yield ($t\ ha^{-1}$)	Hills harvested
Malisor-84-1	0.77	101	1.56	127	1.74	100	1.35	109
Malisor-84-5	0.74	92	0.87	108	0.23	30	0.61	77
CE-151	0.84	86	1.28	120	1.13	111	1.08	105
CSM 288	0.25	99	0.97	118	0.70	86	0.63	101
CSM 219	0.99	142	1.05	126	1.02	85	1.02	118
Mean	0.79	103	1.09	114	0.88	81	0.92	99
ES+	0.05	4.8	0.29	8.2	0.20	12.1	0.12	5.1
CV%	10	7	37	10	32	21	31	13

1. Each trial sown as a randomized block with two replications; harvested plot size 49 m^2.

Source: IER 1981-90. Rapports des commissions techniques, Sorghum Breeding, 1990.

Table 10. Situation of varieties selected by ICRISAT-Mali.

Introduction	Status	Released for commercial use	Released for experimental use
ICSV-401	Proposed for on-farm trials		
Malisor-1	Limited farmer use-zone ODIPAC		xx
82-S-50	In on-farm trials		
S-34	In on-farm trials		
ICSV-1063	Proposed for on-farm trials		
E-35-1	Completed on-farm trials		
S-6	Dropped after on-farm trials		xx
ICSV-1063	In on-farm trials		
Local Varieties			
CSM-228	Completed on-farm trials		
CSM-219	Completed on-farm trials	xx	
CSM-63	Completed on-farm trials	xx	
CSM-388	In large scale multiplication	xx	
Bred by the program			
Malisor-84-2	Completed on-farm trials		xx
Malisor-84-3	Completed on-farm trials		xx
Malisor-84-4	Dropped after station trials		xx
Malisor-84-5	In on-farm trials		xx
Malisor-84-6	Completed on-farm trials		xx
Malisor-84-7	Completed on-farm trials		xx
	Head bug resistant source		
	Used heavily as parent in breeding program		

Concluding Remarks

The test of any applied plant breeding program will ultimately be the proportion of the total target area sown with the improved varieties. Table 10 indicates the status of the varieties that have come out of the ICRISAT-IER program, and indicates the progress toward this objective. The reasons for the low adoption to date of our varieties are many, and the solution to several are beyond the scope of the ICRISAT-Mali program objectives. However, given the difficulty of increasing the genetic potential for high yields in a very low input production environment, and the lack of exotic sorghum germplasm adapted to Mali, the progress made to date has established a solid foundation for future progress.

The heavy emphasis early in the program on screening for good grain quality appears to have been a sound approach. Also, the approach of relying heavily on local germplasm and using a population breeding approach for its improvement has produced useful breeding lines on which future progress will be made.

It may also have been useful to have used other breeding approaches earlier in the program, and not expected rapid payoff from the population approach. Also, more use could have been made of the continually improving germplasm from other West African programs through biparental crosses and back crossing, followed by pedigree selection.

The establishment of the cereal technology laboratory to help the breeders improve their selection efficiency was a major accomplishment, and will continue to contribute heavily in the future. Likewise, the head bug research aimed at developing a large-scale screening technique should allow the development of improved varieties less susceptible to the damaging effects of head bug feeding. In fact, effective interdisciplinary research on insect pests as well as grain molds and foliar diseases should have been developed earlier in the program.

Improved varieties developed through plant breeding have not been widely adopted. It may be wise to again dedicate a portion of the breeding effort to the earlier approach of collecting, testing, purifying, and offering to farmers the local landrace varieties with which they are familiar. The relatively modest yield gains that can be expected are likely to be outweighed by the relatively easy adoption and the stable production that offering a choice of varieties of differing maturities would give the farmer.

This may be the most that can be expected until the economic position of the sorghum producer is such that he will be able to significantly improve his cropping system. Eventually, as the rural infrastructure improves and commodity research teams are formed in an improved agriculture research system, the continuation of the approach outlined earlier in this document will show its benefits.

Pearl Millet

Objectives, Methods, and Priorities

Pearl millet is more drought tolerant on sandy soils than sorghum, and can be extended further into regions where rainfall is limited. The principal pearl millet growing areas in Mali are the Segou region (52%), the Mopti region (17%), and the Koulikoro region (15%). Yields on farmers' fields are low, averaging about 700 kg ha^{-1}, although research trials have yielded 1.5-2.5 t ha^{-1}, depending on variety and rainfall zone.

Pearl millet is usually grown as a sole crop, but there are substantial areas of pearl millet/cowpea intercropping in the drier regions, while pearl millet/maize intercrops are found in higher rainfall zones. Sorghum/pearl millet and early pearl millet/late pearl millet intercrops are also grown. Pearl millet is often preferred over sorghum (Fig. 3), but the lack of good markets and the poor pricing structure limit the adoption of new production technology by farmers.

The two objectives of the pearl millet breeding program are:

- to improve the productivity of the local germplasm (Fig. 4), and
- to breed for yield stability through better tolerance to biotic and physical stresses.

The methods used to obtain these objectives are:

- to improve local populations by selecting for larger panicles, bolder grains, and better tillering;

Figure 3. Pearl millet is a multiple-use crop. The stalks are a good roofing material.

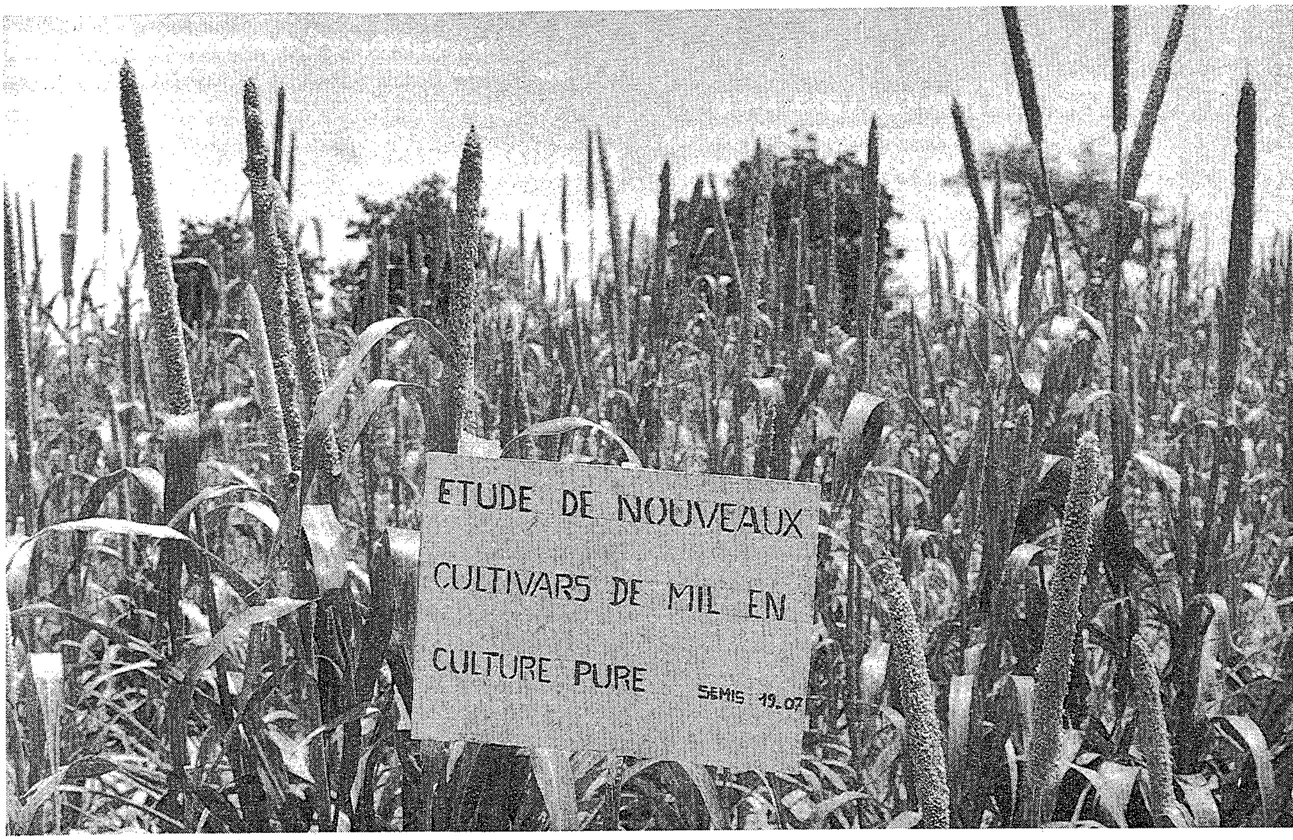


Figure 4. Pearl millet plots at Koporo research station were planted to study genotype response to plant population (33 000 and 66 000 plants ha^{-1}) and fertilizer levels.

- to create composites and synthetic varieties by using local and introduced materials; and
- to increase the harvest index by breeding dwarf synthetics, and later F_1 hybrids.

Table 11 lists the research priorities of the current pearl millet breeding program in Mali.

Achievements

A major milestone for pearl millet research–and many other areas of agricultural research in Mali–was the construction of the research station at Cinzana. This station has the administrative backup, research staff, and good laboratory and field facilities to conduct comprehensive research on pearl millet improvement. This work is currently directed by Dr Oumar Niangado, assisted by Malian research staff. A chronology of pearl millet breeding in Mali during the span of ICRISAT-Mali program is given in Table 12.

Table 11. Ranking of pearl millet breeding priorities in the three agroecological zones of Mali.

	Zone		
	Sahelian	Sudan-Sahelian	Sudan-Guinean
Objectives			
Yield stability	1	2	
Yield increase		3	1
Criteria			
Varietal resistance to:			
Raghuva spp	1		
Acigona	2	3	
Downy mildew	3	3	2
Smut	3	3	
Ergot		3	
Striga	1	1	1
Drought	1	2	
Improved harvest index		3	1
Response to fertilizer		3	1

Source: Niangado and Traoré 1988.

Table 12. Chronology of pearl millet breeding in Mali.

Years	Breeders	Highlights
1979-82	J. Scheuring	Local germplasm collection and evaluation Introductions from ICRISAT Center in India Selection for improved harvest index
1982-84	J. Scheuring O. Niangado	Recurrent selection in local varieties Intervarietal hybridization Development of downy mildew screening nursery
1984-90	O. Niangado	Improvement of composites Formation of synthetic varieties Evaluation of introductions from ICRISAT Sahelian Center Evaluation of F_1 and topcross hybrids

Cooperative programs with the ICRISAT Sahelian Center (ISC) and other international agencies are in progress, and a diverse germplasm base for pearl millet improvement has been established. From 1975 through 1986 some 1200 accessions were collected by various agencies, approximately 75% of which are cultivated forms.

Early work on pearl millet improvement in Mali resulted in several improved local varieties. Of these M_2D_2 and NKK are early types, and NBB, M_9D_3, and $M_{12}D_3$ are medium-late. Yields from these varieties in research station trials were somewhat improved over local varieties, but yield potential was limited. Yield trials for early and medium-late pearl millet varieties are shown in Tables 13, 14, and 15.

At the beginning of the ICRISAT-Mali program, pearl millet improvement via reselection of local varieties was deemphasized, and two other breeding schemes were expanded. One was the use of introduced varieties as well as local material to create composite populations from which synthetic varieties could be obtained using recurrent selection and S_1 testing schemes. The other breeding scheme was a program aimed at improving harvest index (improving grain yield potential while reducing plant height). This program used a partial backcrossing system.

The Souna × Sanio and Pool 4 composites from the recurrent selection (synthetic) program appeared promising. A second cycle of recurrent selection in these two composites was made in collaboration with ISC. The best selections were recombined and experimental varieties from this breeding cycle are being evaluated. In addition, two introduced varieties, IBV-8001 and ITMV-8304, have been identified for further testing in Mali. Table 16 lists the status of selected pearl millet cultivars in Mali.

Under favorable conditions, some improved pearl millet varieties yield up to 25-30% more than local varieties,

Table 13. Yield of pearl millet cultivar NBB (kg ha^{-1}) compared with other cultivars at three locations in Mali.

	Locations			
Cultivar	Sotuba	Katibougou	Kita	Mean
Compel C_0	1640	2360	880	1626
NBB S_2-R	2720	2600	790	2037
Pool 6 C_0	1180	1320	1790	1430
M_9D_3	2270	2910	1730	2303
Control	2090	2940	940	1990

Source: Niangado and Traoré 1988.

Table 14. Yield of pearl millet cultivar Toroniou (kg ha^{-1}) compared with other cultivars at two locations in Mali.

	Locations		
Cultivar	Cinzana	Katibougou	Mean
Toroniou C_1	1745	1795	1770
NKK	1570	1495	1530
Compel S_3R C_1	1185	1350	1270
Compel OR C_0	1170	1515	1340
M_2D_2	1170	1320	1245
Pool 6 C_0	1140	1220	1180
Local	1060	1280	1170

Source: Niangado and Traoré 1988.

Table 15. Yield of medium-late pearl millet cultivars (kg ha-1) at three locations in Mali.

Cultivar	Locations			
	Sotuba	Kita	Kati-bougou	Mean
NBB S_2R C_1	1770	2720	2360	2260
Compel OR C_0	2320	1640	2600	2190
Pool 6	1020	1180	1320	1175
M_9D_3	2935	2270	2910	2705
Local	2010	2090	2940	2345

Source: Niangado and Traoré 1988.

but under traditional agricultural systems, they may be no better than farmers' varieties.

One area of current work is to improve harvest index using dwarf 3/4 local selections (two populations: one based on M_9D_3 for the higher rainfall zone, and the other based on NKK for lower rainfall areas). Dwarf millets from this breeding scheme lack vigor and yield stability, and seem to suffer more damage from diseases and insects. Preliminary studies indicate that vigor and resistance/tolerance to diseases and insects can be recovered by shifting to an intermediate height plant—one that still results in a desirable harvest index ratio.

There have been some limited efforts to breed hybrid pearl millets. None of the introduced hybrids or male sterile lines are adapted. It appears that male-sterile seed parents would have to be based on local varieties if hybrids are properly assessed under Malian conditions.

Disease and insect resistance are important factors contributing to yield stability under the harsh climatic conditions that characterize much of the pearl millet production area in Mali. The establishment of a downy mildew screening nursery at the Cinzana station, in collaboration with ICRISAT Center, is a major accomplishment to continue resistance breeding. Several pearl millet cultivars with good resistance have been identified so far, the most promising of which is line 804. Screening techniques also need to be developed for smut, head caterpillars, stem borers, and *Striga*.

Researchers at the Cinzana station have developed a screening system to identify plants and lines which have desirable stand establishment characteristics. This involves techniques for heat and drought tolerance (charcoal application to raise surface temperatures), and for sand burial.

Concluding Remarks

The low production environment in which pearl millet is generally grown is a serious constraint to the adoption of improved varieties. In such low-input production systems, plant breeding cannot be expected to have much impact at the farm level. Thus the first increment of yield gain could be made more easily with improved management practices, if it were feasible for the farmer to make the necessary inputs, and improved practices to control constraints such as *Striga*.

Pearl millet breeding research should be regionalized within Mali, with specific objectives for each region. The constraints differ in each region. In the north, breeders should select for yield stability and resistance to downy mildew, insect pests, and drought after flowering.

In the south, breeding strategy should be oriented to intensify cropping systems, and for material that responds

Table 16. Status of selected pearl millet cultivars in Mali.

Category and source	Number of cultivars			
	Selected	In catalogue	Adopted	On-farm trials
Introductions				
ICRISAT/ISC	3	2		
INSAH/NARS/ICRISAT	6	5	2	2
ICRISAT CENTER	1	1		
Local varieties				
IER/ICRISAT	5	3	2	2
Composites				
IER/ICRISAT	6	2		3

to inputs, has downy mildew tolerance, and an improved harvest index.

Pearl millet breeders should work with food technologists to explore alternative uses for the crop as feed, forage, and food. Training additional plant breeders should remain a high priority.

Section 4

Agronomy and Cropping Systems Research

Agronomy and Cropping Systems Research

General Objective and Background

The primary research objective of the ICRISAT-Mali program has been to develop improved sorghum- and pearl millet-based cropping systems appropriate to Malian agriculture which have the potential to increase production of one or both of the component crops. Although mixed cropping (sowing more than one crop in a field, although not always in regular order or in predetermined proportions) is very characteristic of subsistence agriculture in Mali, it had not been an area of research prior to the ICRISAT-Mali project.

The prior assumption was that agricultural production would increase through a shift from mixed to pure cropping, not from improved mixed cropping systems. This approach was based on the colonial system of export crop production, primarily cotton and groundnut, in which the objective was to maximize the yield per hectare of a single crop using a substantial level of inputs.

This model is hardly applicable to the objectives of subsistence agriculture, which seeks to maximize return to labor rather than to land, to produce several crops, and which has potential access to inputs only if one of the component crops has a market potential.

Intercropping, primarily of cowpeas in millet or sorghum and also millets in maize or sorghum, is very widely practiced by Malian farmers. After initial investigations of traditional farmer practices, the agronomy program helped to develop experimental approaches to examine the potential for intensification of these traditional systems. Consultants from ICRISAT's program in Burkina Faso and ICRISAT Center participated in this initial process.

Intercropping research gained credibility with IER following an initial demonstration by the ICRISAT-Mali agronomy program of the yield advantages per given area of selected crops when they were grown in combination rather than as sole crops.

The initial acceptance of research on intercropping in Mali was a result of earlier visits by the senior scientists and administrators of IER to ICRISAT Center in India which had a major research program on intercropping. The Director General of IER at that time noted that he was particularly impressed with the importance ICRISAT had placed on intercropping at the Center and requested that a similar emphasis be adopted in Mali.

ICRISAT Center in India has documented the magnitude of the biological advantages of selected intercropping systems and the scientific bases for these advantages, some of which are clearly applicable to Malian agriculture. For example, a system which combined subsistence cereal crops (sorghum or pearl millet) with a market crop (groundnut) could justify the use of modest levels of fertilizer because of the market value of the non-cereal crop.

The ICRISAT-Mali program therefore focused research on intercropping in order to identify appropriate systems which could be made available to extension and development programs. This research has been conducted by a multidisciplinary team, with the ICRISAT-Mali program assuming a leadership role (Fig. 1). Many *cellules* of IER increasingly contributed to this cropping systems research program.

Research Focus

Since 1977, the number of research staff who have been trained has increased, and their training has improved the quality of research. Along with improved research station facilities, the agronomy program has grown considerably from its original size and focus. Initial research on traditional intercropping systems has been completed, and these systems have been passed to SAFGRAD and CEMP for on-farm tests.

New research objectives have been added in response to suggestions made in program evaluations and to opportunities and needs arising from breeding new sorghum and pearl millet varieties, in addition to the increased research capability of the Cellule agropédologie (AGP) of SRCVO, to which the ICRISAT-Mali agronomy program is attached.

Since 1985, the research program has had four major areas of concentration:

- Agronomy of selected intercrop systems. These experiments are evaluating management alternatives, mainly choice of variety, for intercropping systems which have already proven successful. These experiments represent a second stage of the initial research on the systems themselves.
- Potential new intercropping systems for both sorghum and pearl millet, including both new component crops and new management practices. These experiments include pure crops of the components to estimate biological advantages of new systems.
- Agronomy of new varieties of sorghum and pearl millet. These experiments evaluate the response of new varieties to changes in plant population, sowing date, fertilizer level, and other factors in comparison to the responses of standard varieties. These trials also pro-

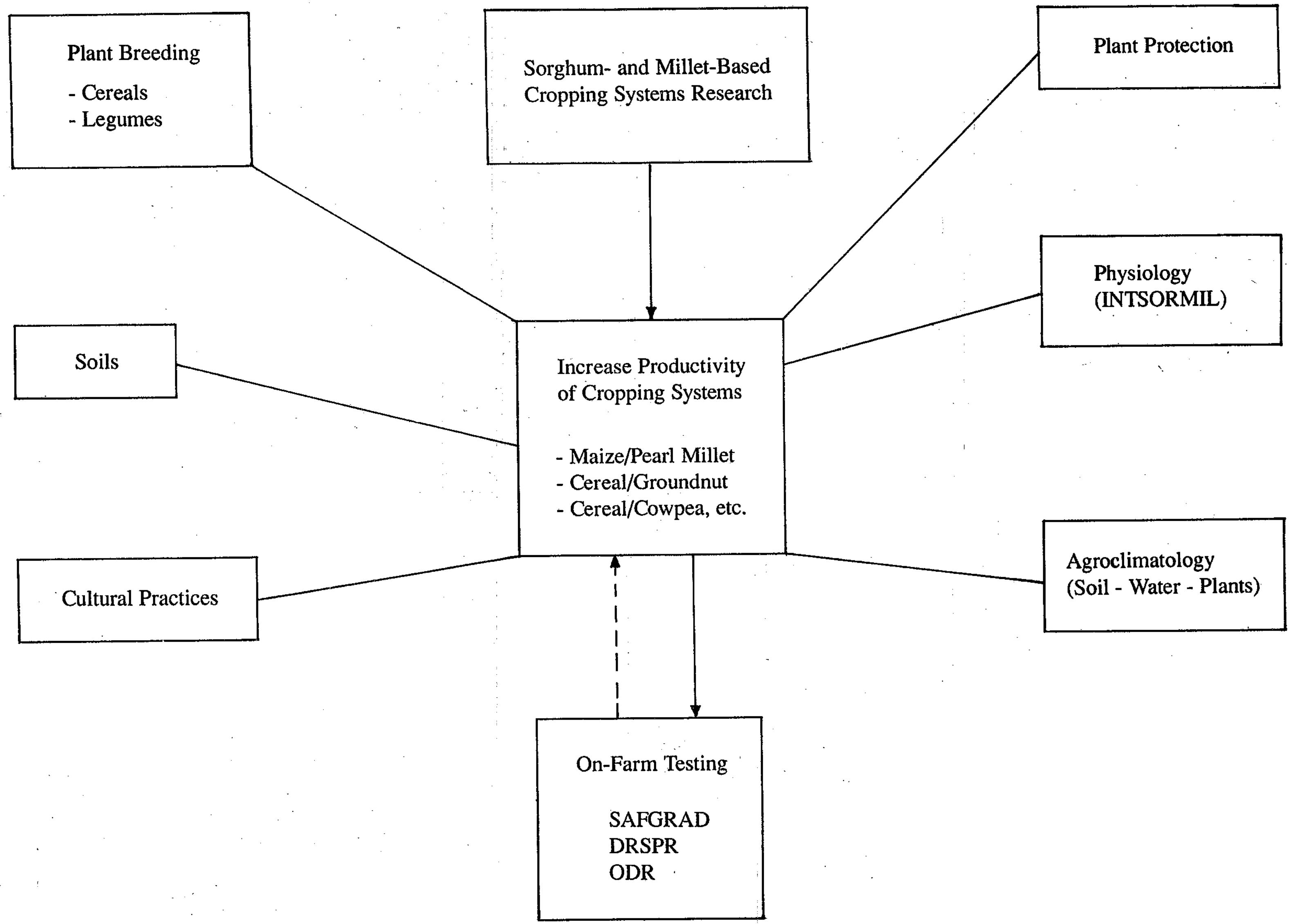


Figure 1. Structure of the multidisciplinary research on cropping systems in Mali.

vide the data necessary to recommend management practices for new varieties.

- Evaluation of recommended production technologies for both sole and intercropping systems. These are a series of researcher-managed, experiment station trials designed to evaluate the potential yield responses to improved soil preparation, addition of fertilizer, and use of improved varieties. Such trials, repeated over years and locations, provide the basic data from which to recommend new technologies to extension and development agencies.

Research on cropping systems improvement was chosen as the focus of the agronomist's work for several reasons:

- The systems chosen for detailed research were already widely practiced by Malian farmers in the agroclimatic zones for which they are targeted. Problems of acceptance of these systems by farmers are thus minimized.
- The systems chosen combine a subsistence cereal with a crop with a commercial potential which can justify an increased level of inputs to the system. Although certain commercial crops may ultimately be produced as sole crops, the production of these at the initial stage in an intercropping system reduces the risk to farmers from both climatic and market variability, and provides subsistence requirements within the same cropping system.
- With the present low yields in Mali, it is likely that initial increases in production will come from increased inputs, mainly fertility, and improved crop management, rather than from new varieties. Cropping systems agronomy provides a way to raise both input and management levels to the point where the superior yield potential of new varieties can have an impact on national production.

Other Activities of the Agronomist

The cropping systems agronomist, particularly during Phase I, was heavily involved in experiment station development activities at Cinzana and at other IER stations where the ICRISAT-Mali program conducted collaborative research. Similarly, much of the agronomist's time was spent on training activities, including informal training of Malian research personnel and supporting formal training of Malian scientists and technicians at all levels. During the Phase II, the agronomist also organized workshops and meetings for technology transfer to various national program research and development organizations. More details of these activities are in the section on "Strengthening the National Program".

In addition to cropping systems research, the ICRISAT-Mali agronomy program was also responsible for initiating research on animal traction, soil tillage, and the agronomy of secondary crops such as fonio, bambara nut, and pigeonpea. The ICRISAT-Mali agronomists served as team leaders for all but three years of the program.

Research Summary

Table 1 summarizes the agronomic and cropping systems research conducted over the life of the project. Neither the table nor the following discussions are exhaustive, but rather highlight the most significant work. Detailed methodologies and results of agronomic research were published in the annual reports and conference and workshop papers (Annexes V and VI). Other technical publications are being prepared for wider scientific audiences.

Experiment Station Management

This aspect of the agronomy program was conducted primarily during Phase I of the project, and combined research with infrastructure development and training since the existing experiment stations were poorly equipped to conduct field experiments at the beginning of the program. Animal traction systems were developed to prepare land and weed fields because these systems were more relevant to the level of technical and financial resources of the experiment stations. Extensive efforts were made to test and select animal traction equipment and train operators (and animals) to effectively use the equipment. Personnel were also trained to use and maintain various pieces of mechanized equipment, including light tractors.

In order to establish the most effective research uses of the different soils at the Cinzana station, crop adaptation trials were planted along the station toposequence. These studies were supported by an extensive soil survey and vegetation analysis of the entire station site. Soil conservation measures such as contour bunds and grassed waterways were also established.

The research and training that was done during this period played an important role in improving the capability of the Cinzana, Sotuba, and Koporo stations to conduct agronomic research. The quantity and quality of research conducted on these stations in later years has been a direct benefit of station management work during 1978-1983.

Soil Management Research

Although soil management has not been a priority of the

Table 1. Summary of agronomic and cropping systems research, 1978-1990.

	Years topic was researched												
Research topic	78	79	80	81	82	83	84	85	86	87	88	89	90
Expt station management													
Animal traction	xx	xx	xx	xx	xx	xx							
Machinery		xx	xx	xx	xx								
Land use		xx	xx	xx	xx								
Training[1]	xx	xx	xx	xx	xx	xx	xx						
Soil management													
Land preparation[1]	xx	xx	xx	xx	xx	xx		xx	xx	xx	xx	xx	
Watershed studies	xx	xx	xx	xx	xx								
Traction equipment[1]				xx	xx	xx	xx	xx	xx	xx	xx	xx	
Cereal/cowpea association													
Agronomy	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
Varieties		xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	
Fertilization[1]						xx			xx	xx	xx	xx	
Maize/millet association													
Agronomy					xx	xx	xx	xx	xx	xx	xx	xx	xx
Varieties					xx	xx	xx	xx	xx	xx	xx	xx	
Fertilization[1]					xx	xx			xx	xx	xx	xx	
Cereal/groundnut association													
Agronomy								xx	xx	xx	xx	xx	xx
Varieties										xx	xx	xx	xx
Fertilization[1]											xx	xx	
Striga incidence[1]										xx	xx	xx	xx
Systems for Guinean zone													
Maize systems										xx	xx	xx	xx
Sorghum systems											xx	xx	xx
Alternative crops													
Pigeonpea	xx	xx										xx	xx
Finger millet		xx	xx	xx	xx	xx							
Fonio[1]							xx	xx	xx	xx	xx	xx	xx
Forage species			xx	xx									
Voandzou[1]							xx	xx	xx	xx	xx	xx	xx
Agronomy of new varieties													
Sorghum[1]			xx	xx			xx	xx	xx	xx	xx	xx	xx
Millet[1]								xx	xx	xx	xx	xx	xx
Recommended technology assessment													
Sole crops[1]										xx	xx	xx	xx
Intercrops[1]												xx	xx
OPSCAR[2]											xx	xx	xx

1. Cooperative research project with other scientists and sections in SRCVO.
2. Operational Scale Agricultural Research (cooperative research project with ICRISAT Sahelian Center, Niamey, Niger).

ICRISAT-Mali agronomy program because this has been the major focus of other collaborative institutes and projects such as IRAT, TROPSOILS, and Project Agropedology (funded by the Netherlands), a number of management alternatives were studied in the intercropping systems work, toposequence experimentation, agronomy trials, and the experiment station management work. This work is now done cooperatively with the Cellule AGP of SRCVO, and is a component of both intercropping agronomy, graduate thesis studies, and new variety agronomy.

Trial results have shown consistent, positive responses to plowing, frequent positive responses to ridging, but infrequent positive responses to tied ridges. Yield responses to plowing are consistent with the results of earlier IRAT work, and support the present extension efforts to increase the use of animal traction for land preparation in Mali. Limited work continues on the improvement of animal traction equipment through consultancies by an agricultural engineer from ICRISAT Center.

Initial work on animal traction included the evaluation of wheeled tool carriers obtained from ICRISAT Center, which were introduced for research station work. This equipment proved efficient and attracted considerable attention by researchers and development agencies, but adoption by farmers was neglibible because the equipment is too expensive.

Recent work has been on the development of light weight, donkey-drawn cultivating and sowing equipment which is now used at the Koporo and Cinzana stations (Awadhwal et al. 1990). There is good potential for using the donkey as a draft animal in the West African semi-arid tropics where the soils are light and sandy. A low-cost cultivator and seeder was designed, developed, and tested in Mali to replace the existing donkey-drawn iron implements, which are too expensive. It was fabricated at the workshops of the Division du machinisme agricole and the largest manufacturer of farm implements in Mali.

This cultivator and seeder is simple and can be fabricated from locally available materials. Farmers can expand the area under cultivation because seeding and weeding operations can be completed faster. The cultivator can be used for interrow weeding and presowing shallow tillage, and covers about 0.1 ha h^{-1}. The seeder can sow pearl millet and sorghum in hills about 50 cm apart and in rows spaced at up to 90 cm. It covers approximately 0.2 ha h^{-1} when rows are spaced 50 cm apart.

Intercropping Systems

While conducting research on intercropping systems (Figs. 2-4) in Mali, several principles were considered (Shetty et al. 1987a):

- Agronomic and varietal improvements were designed for the intercrop as a single system, not for the individual crops within the intercrop.
- One of the crops was considered the principal crop and the other secondary. The primary goal was to maintain the yield of the principal crop and improve the yield of the secondary one.
- The measurement of intercropping advantage (land equivalent ratio–LER) was not considered as a major objective. Therefore, the performance of each of the components within the intercrop was not always compared with its performance as a sole crop. The major goal was to improve the traditional intercropping system as a whole.

Figure 2. An experimental plot of pure groundnut (foreground) is planted adjacent to a plot where maize has been harvested from between rows of pearl millet and relay-planted cowpea.

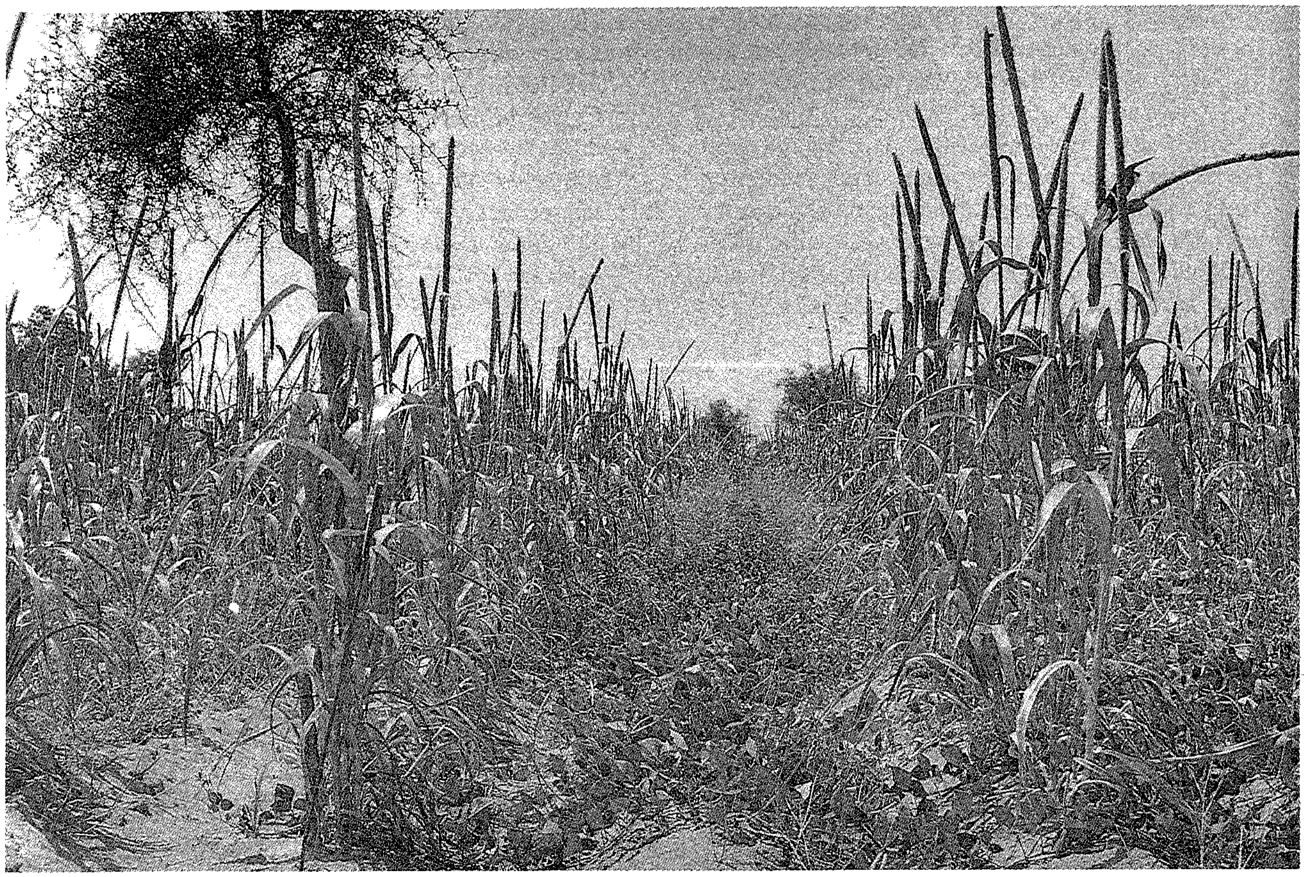


Figure 3. In an OPSCAR (operational scale agricultural research) experiment at the Koporo research station, five different pearl millet treatments were planted varying use of fertilizer, method of intercropping cowpea, use of animal traction, and rotation.

Table 2. Some characteristics of the intercropping systems studied by ICRISAT-Mali.

System	Regional importance	Type	Development and growth cycle	Main crop	Expected economic return
Pearl millet/ cowpea	Very important (north and central areas)	Cereal/ legume	Cowpea first, then cereal	Pearl millet	Good
Sorghum/ cowpea	Very important (entire country)	Cereal/ legume	Cowpea first, then cereal	Sorghum	Good
Maize/ pearl millet	Very important (south)	Cereal/ cereal	Maize, then pearl millet	Maize	Superior
Cereal/ groundnut	Not much known, potential is high in groundnut zone	Cereal/ legume (cash crop)	Groundnut, then cereal	Groundnut	Very good
Maize/pearl millet/cowpea	Can be important in south	Three crops	Maize, cowpea, pearl millet	Maize	Very good

Figure 4. A traditional pearl millet/cowpea intercrop where *Striga gesnerioides* has infested the cowpea.

- Only a low level of inputs was considered.
- In general, all the improvement work was aimed at grain yield, and forage yield was not always considered.

Table 2 shows some characteristics of the intercropping systems which were studied, and Figure 5 shows the relative growth over time of the component crops of selected systems.

Cereal/Cowpea Associations

The first intercropping system chosen for study was cereal/cowpea because it was already widely practiced in the dry and intermediate rainfall zones of the country. The objective was to increase the cowpea yield (grain and/or hay) by increasing the population of cowpea in the system, but without substantially lowering the pearl millet or sorghum yield (Serafini 1985).

A variety of management treatments were used to manipulate the competition between the two crops. Successful manipulations included the addition of modest rates of nitrogen fertilizer to the millet, slight delays in sowing the cowpea with a compensatory increase in sowing rate, earlier harvest of cowpea in a system designed for hay production only, and sowing the two crops in alternate rows rather than alternate hills.

Land equivalent ratio (LER) averaged about 1.3 for the better treatments, indicating about a 30% gain in the biological efficiency of such systems. LER is the ratio of the amount of land required to produce the same yield of the two crops grown as sole crops to that required when grown as an intercrop.

More recent experimentation under the leadership of AGP has focused on the response to fertilizer of the optimum cereal/cowpea systems, and the comparative performance of different genotypes in these systems.

Results of the latter trials suggest that choice of variety can have substantial effects on both LER and profitability of the system, due to both the inherent yielding ability of the variety and the degree of competition it provides to the companion crop. Addition of N fertilizer improved the overall productivity of the system.

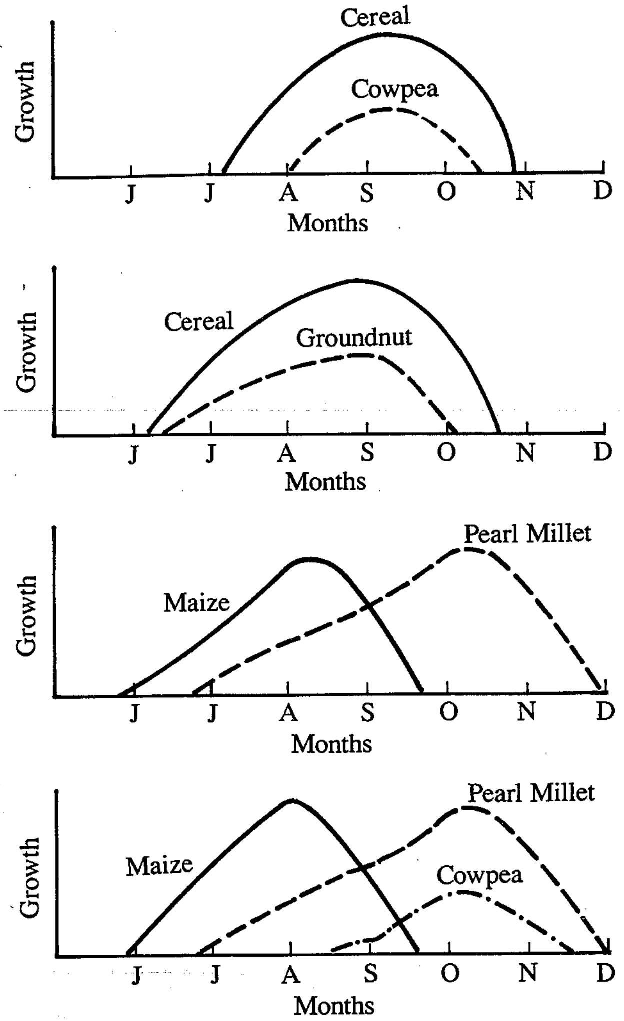


Figure 5. Growth over time of four cropping systems studied by ICRISAT-Mali.

Results of specific treatments (Shetty et al. 1987b, Serafini 1985) include:

Cowpea Density. With slightly delayed planting, increasing the cowpea density to about four times the traditional 6000 plants ha^{-1} improved cowpea yields without significantly affecting the pearl millet yields. Vigorous, dense pearl millet is usually able to grow above the cowpea even at relatively high cowpea density. However, if the cowpea got ahead of the pearl millet where seedling establishment was poor, even 10 000 plants ha^{-1} of cowpea could reduce pearl millet yields.

Cultivar. In the absence of improved pearl millet cultivars most of the early studies were conducted with local varieties. Without insecticide treatment the local cowpea yielded better than improved varieties, but improved cowpea was better for maintaining pearl millet yields.

When sorghum and cowpea were grown in an intercrop during the 1988 and 1989 seasons, Malisor 84-7 and Sakoika encouraged more cowpea forage production. Among cowpea varieties, KN1 and TVU 76-07 performed better than the local variety Amarysho for forage, but for grain production Amarysho performed better than the other two. Malisor 84-7 and Malisor 84-1 produced less dry matter than the local Sakoika (Sogodogo and Shetty 1990b).

The combination of Malisor 84-7 sorghum and KN1 cowpea produced the highest forage yield, but for grain Sakoika sorghum and Amarysho cowpea were best.

Intercrop Seeding Date. Planting cowpea on the same day as pearl millet favored cowpea development at the expense of pearl millet growth and yields, especially when moisture and fertility were limiting. Slight delays (7 d) in cowpea seeding removed most of the negative effects of the cowpea on pearl millet yields. Cowpea hay yields, however, were significantly reduced by delays in seeding. Higher cowpea densities planted late maintained better cowpea yields without compromising pearl millet yields.

Cowpea Harvest Schedule. Early cowpea harvest favored both pearl millet and cowpea yields. Early harvest often removed the negative effects of higher cowpea densities and early cowpea plantings on cereal yields. There were also occasional increases in pearl millet yields, perhaps due to nitrogen release from the decomposition of cowpea residues during the pearl millet grain-filling period after the cowpea harvest. The best total yields (pearl millet and cowpea fodder) were obtained with early-planted, high-density cowpea harvested 60 d into the season.

N-Fertility. In most cases adding nitrogen to pearl millet resulted in higher productivity of the system. Pearl millet responded to nitrogen without significantly affecting cowpea yields. An early-planted, high-density cowpea intercrop compromised cereal yields in the absence of adequate N for the pearl millet. The negative effect of higher density cowpea can be removed by adding N to the millet.

Maize/Pearl Millet Associations

The maize/pearl millet intercrop is an ideal combination because the growth cycle of the maize (100-120 d) and the millet (150 d) are sufficiently different that competition between the two is at a minimum. Such a system allows full use of the 5-month rainy season in southern Mali to produce two harvests rather than one (Shetty 1989).

Research to intensify the system, which is already commonly practiced by farmers, began in the early 1980s when CMDT began assisting farmers with both inputs and marketing for maize as a rotation crop with cotton. Because the emphasis was on maize, the research goal was to maintain the full yield potential of maize as a sole crop (for sale), while increasing pearl millet for consumption as much as possible.

Research results indicated that the best management practice was to sow a full stand of maize, and at the 3-4 leaf stage transplant or sow one row of pearl millet to each two rows of maize, and provide substantial levels of nitrogen fertilizer to the system. The best management system gave LERs in the 1.4-1.5 range, combining maize yields of 2.3 t ha^{-1} with 0.6-0.8 t ha^{-1} of pearl millet (Shetty 1989).

Early sowing of the pearl millet intercrop generally increased pearl millet yields at two sites. Pearl millet sown along with maize caused a marked reduction in maize yields, while delays in sowing pearl millet after maize reached the 3-4 leaf stage reduced pearl millet yields. When pearl millet was sown after the maize, increasing its seeding rate increased its yield without markedly reducing maize yield. Increasing maize density to the normal level for a sole crop increased maize yield and decreased pearl millet at a northern, drier site, but did not significantly reduce yield at a southern site where soil moisture was better (Serafini 1985).

Two levels of added N fertility, 40-60 kg ha^{-1} and 80-120 kg ha^{-1}, were compared because maize usually receives additional fertilizer. Maize responded to higher fertility in 1982 when rainfall was adequate, but in the dry year of 1984, there was no difference. Although interactions were not significant, there were indications that maize responded better to N when pearl millet was planted later, and that the yields of the later-sown pearl millet intercrop could be maintained by increasing its density. Early seeding of the pearl millet eliminated the effect of the higher N level on the maize (Serafini 1985, Shetty et al. 1987a).

In 1985, the effects of variety, density, and N-fertility on productivity were evaluated on an operational scale. The local maize landrace performed as well as the recommended improved variety, Tiemanchie, in all locations. Higher maize densities did not result in higher maize yields. Maize, however, did respond significantly to added N (Shetty 1989).

This more intensive version of a traditional system moved rapidly from the agronomy program research fields to the pre-extension testing stage in the CMDT zones. Adoption by farmers was good as long as CMDT was able to support maize production, but fell when CMDT withdrew its support when it could no longer market the maize.

The system remains viable and productive, and could be readily intensified if market conditions improve. More recent work on fertilization and choice of maize variety has increased flexibility to vary the relative production of the two crops in the systems as farmer objectives change.

Cereal/Groundnut Associations

Research on cereal/groundnut intercrops began in the mid-1980s as an alternative to the cereal/cowpea systems in the intermediate rainfall zone. Significant grain production in cowpea in this zone is virtually impossible without using insecticides. Low market prices for cowpea make use of insecticide economically questionable in traditional systems in which the cereal is the major component. These systems also differ from cereal/cowpea intercrops because they are managed to maximize the groundnut yield with 50% of the sole crop cereal yield, rather than attempting to maintain the sole crop cereal yield (Shetty 1989).

Research trials have indicated that in this system, yield can be improved by maintaining a high groundnut population and a reduced cereal population (four rows of groundnut to one of cereal), applying N to the cereal rows, and using earlier-maturing varieties. On-station results have indicated that yield improvements can be achieved from maintaining about 200 000 plants ha^{-1} of groundnuts with about 50 000 plants ha^{-1} of cereal, applying N at 23 kg ha^{-1} to the cereal, and using earlier-maturing cereal varieties planted simultaneously with groundnut (Shetty et al. 1990).

LERs from these systems have averaged about 1.2 to 1.3, somewhat below that of the cereal/cowpea systems, because there is less difference in the life cycles of the two crops. Profitability depends largely on maximizing groundnut yield because of its higher market price. Multilocational on-farm tests have confirmed this on-station research.

A potentially useful finding from this experimental work seems to be significantly reduced *Striga* incidence in the intercrop with groundnut compared to the sole crop of cereals. Studies have shown that the number of *Striga* emerged in the intercrop was about one-third of that observed in a pure cereal crop. The physiological reasons for this phenomenon are being investigated (IER 1990).

The research on cereal/groundnut systems has attracted considerable attention in Mali. It is believed that growing cereal/groundnut intercrops would enable cereals to benefit from added inputs to groundnut and thus result in higher overall productivity. Further, the strategy

Figure 6. Experiment designed to evaluate agronomic factors in a sorghum/groundnut intercrop: varieties, added fertilizer, and land preparation method.

Figure 7. Sorghum and groundnut are planted as an intercrop (foreground), while sole sorghum grows in the background. The tall sorghums are late, traditional varieties, while the shorter cultivars are improved and of medium maturity.

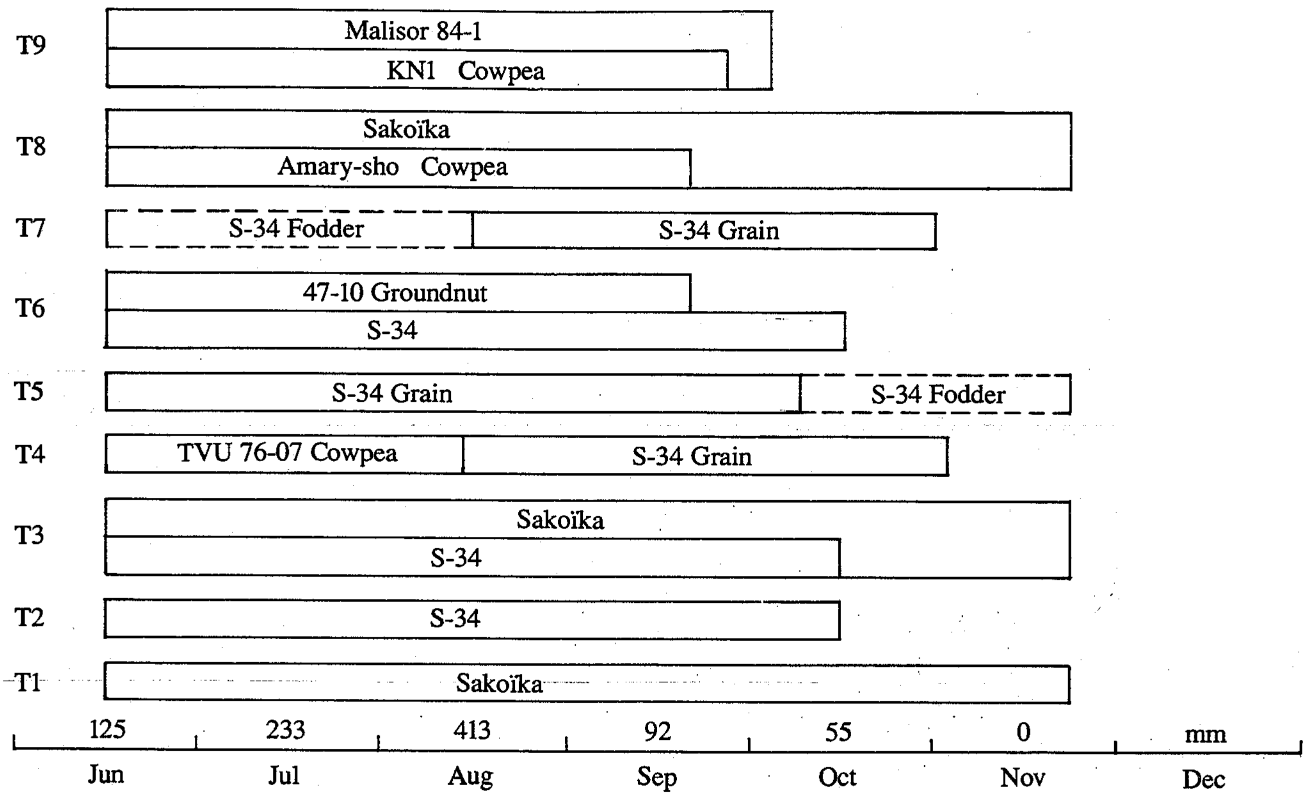


Figure 8. Duration of different sorghum-based cropping systems (treatments evaluated T1–T9) in relation to mean rainfall (1988 and 1989 at Sotuba) in the Sudano-Guinean Zone of Mali.

of including a higher value crop such as groundnuts could provide income to farmers and as a result stimulate the use of inputs on traditional cereal crops. More productive cropping systems such as these could also attract and support management-responsive cereal cultivars being developed by crop breeders (Figs. 6-7).

Systems for the Sudano-Guinean Zone

In 1987, research began on new cropping systems to take fuller advantage of the long rainy season in the Sudano-Guinean Zone (Fig. 8). This research is investigating the potential of relay cropping and ratooning, as well as improved intercropping systems (Sogodogo and Shetty 1990a).

In general, sorghum yields were highest from sole crops and intercrops with cowpea and groundnuts, compared to sorghum as a component of a sequential, relay, or ratoon cropping system. Crop establishment during the turn-around time and early cessation of rains were problems.

Some sorghum cultivars ratoon better than others, but the local sorghum has the least potential for ratooning because of its long growth cycle. Ratoon cropping in Mali (and West Africa) is not well known, but studies have shown the potential of this new system. Those sorghum cultivars which ratoon better than others have been identified for further research. Considerable interest has been expressed in this new system by research and extension agents.

In southern Mali where the potential growing season is longer, ICRISAT-Mali demonstrated that growing three crops (maize, pearl millet, and cowpea) is possible. Agronomic research is underway to improve the potential of such sequential and three-crop systems, and to select cereal varieties which maintain their potential yields when sown later in the season as relay and sequential crops (Fig. 9).

Alternative Crops

During Phase I of the project, research trials on alternative crops (Fig. 10) for food and fodder were started, but following the recommendation of the 1983 mid-term re-

Figure 9. In this experimental plot, maize which was planted between rows of pearl millet has already been harvested, and a late-planted crop of cowpea is a relay crop among the pearl millet.

view, most of the work was discontinued so that work could focus on developing recommendations for a few selected intercrop systems. At the request of SRCVO, however, work began in 1988 on the agronomy of two common secondary crops, fonio and voandzou (bambara groundnut).

Results of the earlier work indicated that both finger millet and pigeonpea can be grown successfully in Mali, but neither seems to have an immediate potential because consumers are not interested. Pigeonpea work began again in 1989, however, as a component of an intercrop (Fig. 11). Similarly, several new forage species appeared promising.

In contrast, fonio and voandzou are widely grown. Initial agronomic studies have shown that these crops do not respond much to added fertilizer, increased plant populations, or improved soil management, indicating that the present varieties seem to have limited yield potential. Evaluation of genotypes collected from different regions of Mali and neighboring countries is now in progress. In a recent experiment, voandzou responded to ridging and added P (IER 1990).

Agronomy of New Cereal Varieties

Research on the agronomy of new varieties from the ICRISAT-Mali breeding program began in 1984 in collaboration with AGP staff, in response to a recommendation from the 1983 evaluation. This work has evolved into a fairly large series of experiments designed to compare the response of new and standard varieties to:

- increased fertilizer and plant populations (intensification of production),
- intercropping in comparison to sole cropping, and
- planting date (to evaluate adaptation to cropping systems requiring a delay in planting of the cereal).

These experiments have produced a large volume of

Figure 10. At the Sotuba research station, the ICRISAT-Mali program conducted agronomic evaluations of sorghum cultivars (background). In the foreground, sesame is being evaluated as an alternative crop for oil and dye in Mali.

Figure 11. An intercrop of improved sorghum and improved pigeonpea. The crop in the background is a local, traditional sorghum.

data (IER 1981-90) which are being summarized, but some generalizations are drawn (USAID 1989):

- In general, new varieties have not had a level of superiority in grain yields over standard or local varieties that might have been expected. Only when yield levels exceeded about 2 t ha^{-1} were there demonstrable advantages of new varieties. These yield levels, however, were not attained in the majority of experiments.
- Some variety × fertilizer interactions were indicated, but only when yield levels reached 2 t ha^{-1} or more.
- New and standard varieties did not respond to increased plant density with any consistent differences.
- There were often large effects of variety in intercropping systems, due to both the degree of competition with the other component and the variety itself. As noted previously, there seem to be potentially large varietal differences for adaptation to intercropping.
- There was some evidence of genetic difference in the ability to maintain yield in later sowing dates, although not necessarily only between new and standard varieties.

Thus the research on intensification indicated that many of the local varieties have adequate yield potential to exploit at least the first stage of intensification as effectively as new varieties. Indeed, in some operational-scale trials the yields of local cereal cultivars doubled with improved agronomic practices.

In addition, there was evidence from several low-yielding experiments and treatments that the new varieties are not as tolerant of such low yield conditions as are the local varieties. This is not surprising, because at the very low yield levels characteristic of much of Malian cereal production, yield potential is not an important determinant of actual yield.

What is of more concern, however, is the frequent inability of increased fertilizer levels and plant populations to push yields up to levels where the improved yield potential of the new varieties is evident. There were cases where this did occur, but they were often the exception, not the rule.

Testing Recommended Technology

Assessing new technology began in 1987 as single 3 × 2 factorial experiment comparing:

- traditional and recommended means of land preparation,
- zero and recommended fertilizer levels, and
- traditional or local varieties and new varieties.

There were two objectives:

- to evaluate the effects and interactions of the individual factors in the recommended "package of practices", because these factors had often been examined in single factor experiments by different groups within SRCVO; and
- to test the potential yield improvement which could be obtained by using these packages in researcher-managed, on-station trials.

Results are being summarized over years and locations, but a general pattern emerges of a consistent, positive response to fertilizer, only an infrequent response to ridging (simple or tied) in comparison to flat planting, and superiority of new varieties generally only under the better yield conditions in sorghum, and only infrequently under any conditions in pearl millet (Sogodogo and Shetty 1991).

Results of recent trials indicated that the yields of a local sorghum cultivar could be doubled (from 1500 to 3000 kg ha^{-1}) with an improved package of agronomic practices. These results thus reinforce the conclusions from the studies on the agronomy of new varieties. The synergistic effects of combining different agronomic practices was noticed with both improved systems and traditional cropping systems (IER 1990).

On-Farm Evaluation of Recommended Cropping System Packages

During the later phase of the ICRISAT-Mali program, new technologies were evaluated to assess their agronomic performance on farmers' fields. Evaluation of productivity, stability, management problems (sowing, weeding, etc.) at the farm level, and general effectiveness in meeting the farmers' production objectives were included. It should be noted that the agronomic evaluation does not include economic evaluation, which is equally important, but often depends upon factors outside the control or knowledge of the agronomist.

Because the ICRISAT-Mali agronomy program is integrated with SRCVO, intercropping systems and crop management practices which had been productive in research station trials were automatically tested in on-farm trials by SRCVO personnel responsible for testing all varieties and production technology.

The ICRISAT-Mali agronomists assisted the Cellule des essais multilocaux et prévulgarisation (CEMP) in planning, executing, and reporting the on-farm research results of the intercropping systems studied.

Five different intercropping systems from the ICRISAT-Mali research program have reached on-farm, pre-extension trials (Table 3). The maize/pearl millet and pearl millet/cowpea systems have completed or will complete 4 years of testing, while the remaining three are only in their third year of testing. The results from these multilocational tests are being synthesized by CEMP personnel. Some early observations from these on-farm tests include:

Table 3. On-farm tests of intercropping systems which are based on research station studies conducted by the ICRISAT-Mali agronomy program.

Intercrop combination	Year of testing						
	84	85	86	87	88	89	90
Maize/pearl millet	xx	xx	xx	xx			
Sorghum/cowpea					xx	xx	xx
Pearl millet/cowpea			xx	xx	xx	xx	xx
Sorghum/groundnut					xx	xx	xx
Pearl millet/groundnut					xx	xx	xx

Maize/Pearl Millet On-Farm Tests. This intercropping system was tested from 1984 to 1987, primarily in the CMDT zone in the southern, cotton-growing region of the country. This coincided with a period when CMDT was supporting maize as a potential commercial crop in rotation with cotton. The trials in 1984 and 1985 compared sole maize and pearl millet crops to two alternative intercropping systems: interrow, as recommended by the agronomy research program, and interhill, as more commonly practiced by farmers (Table 4). Data from these two years were used to evaluate the intercropping system, as well as to compare two systems. The 1986 and 1987 trials compared only the two intercropping systems.

The 1984 and 1985 data indicated biological advantages to the maize/pearl millet intercrop systems on the order of 40% over 35 on-farm trials, similar to the advantages found in on-station trials. Comparison of the two systems across the 4 years showed a statistical superiority of the recommended interrow system in 2 years (1985 and 1987), and a similar performance in 1984 and 1986. The years in which the recommended interrow system was superior were when yields were higher, suggesting that the recommended system will benefit farmers more as the level of management improves.

Overall, the on-farm results provide good support to the on-station conclusions on maize/pearl millet intercropping, and indicate that the technology will benefit farmers in the wetter zones if market prices for maize make this crop attractive to farmers, and where pearl millet is a preferred cereal for home consumption (as is the case in much of the country). This general conclusion is supported by a better rate of adoption of improved pearl millet/maize systems by CMDT farmers.

Cereal/Cowpea On-Farm Tests. SAFGRAD and CEMP trials tested the recommended interrow intercropping of both sorghum and pearl millet with cowpea during 1986-1988 in association with ODIK (Opération de développement intégré de Kaarta) in the sorghum zone, DRA (Division de la recherche agronomique) at Segou, and OHV (Opération Haute Vallée) in the pearl millet zone, on approximately 10 farmers' fields per year per development program (Table 5). Tests in 1986 and 1987 compared farmers' traditional system (usually with a low cowpea population in hills sown among the cereal hills) with the recommended practice of intercropping two rows of cereal to one row of cowpea.

Because cowpea yields were low during these two years, a second interrow system of alternate rows of cowpea and cereal was added in 1988 to increase the proportion of cowpea in the system. These treatments were repeated in 1989. Fertilization of all three systems was similar.

Table 4. On-farm (pre-extension) tests conducted by SAFGRAD/CEMP, comparing traditional maize/pearl millet systems with systems recommended by ICRISAT-Mali agronomy program (Source: IER 1981-90).

Organization/year/crop	Tests	Yield (kg ha^{-1}) Sole crop	Yield (kg ha^{-1}) Row intercrop	LER	Hill intercrop yield (kg ha^{-1})	LER
CMDT 1984	15					
Maize		1578	1409		1059	
Pearl millet		1509	597	1.54	751	1.48
CMDT 1985	20					
Maize		2173	2201		1587	
Pearl millet		1127	494	1.49	504	1.26
CMDT 1986	9					
Maize			1894		1749	ns[1]
Pearl millet			604		594	ns
OHV 1986	9					
Maize			1029		941	ns
Pearl millet			375		301	ns
CMDT 1987	13					
Maize			1925		1613	*
Pearl millet			489		476	ns

1. Significance of interrow vs interhill comparison.
* $P < 0.05$.

Table 5. On-farm (pre-extension) tests conducted by SAFGRAD/CEMP, comparing traditional cereal/cowpea systems with systems recommended by ICRISAT-Mali agronomy program (Source: IER 1981-90).

Organization/ year/crop	Tests	Grain yield (kg ha^{-1}) Farmer system	2 cereal: 1 cowpea	1 cereal: 1 cowpea	Difference[1]
DRA, Segou 1986	7				
Pearl millet		1233	1186		ns
Cowpea		212	33		ns
OHV 1987	10				
Pearl millet		714	90	–	na
Cowpea		69	118	–	na
OHV 1988	7				
Pearl millet		668	686	687	ns
Cowpea		169	182	262	*
DRA, Segou 1988	9				
Pearl Millet		903	877	849	ns
Cowpea		101	169	257	*
ODIK 1987	11				
Sorghum		617	599		ns
Cowpea		101	169		*
ODIK 1988	12				
Sorghum		580	762	571	*
Cowpea		200	315	323	ns

1. Based on paired t-test across trials, with organization × year.
* $P < 0.05$.

During 1986 and 1987, pearl millet yields were similar in the farmer and recommended intercropping treatments in all three project test areas (Table 5). Cowpea grain yields were generally low in both systems, with a significant yield advantage for the recommended intercrop only in the ODIK trials in 1987.

In the 1988 trials, cereal yields were generally similar in the farmers' system and both the recommended intercropping systems. Cowpea grain yields were higher in the 1:1 recommended system than in the traditional system in two of the three project zones, and higher in the 2:1 row system than in the traditional system in one of the three project zones.

More testing of the 1:1 row system was conducted, and the available data seem to demonstrate increased cowpea productivity of the recommended systems, particularly the 1:1 row system, without any sacrifice in the yield of the cereal crop. Plant count data indicate that increased yields were generally associated with increased cowpea density in the 1:1 row combination.

On-farm test data thus again support the results of the on-station research in the cereal/cowpea systems, although the on-farm yields of both crops tended to be lower, and the variability across sites considerably higher. Like the maize/pearl millet system, the improved cereal/cowpea systems seem ready for extension under the appropriate market conditions.

Cereal/Groundnut On-Farm Tests. Cereal/groundnut systems were evaluated in the southern (CMDT) and central (Segou and Kayes region) in Mali during 1988 and 1989. LERs with improved cereal systems ranged from 1.1 to 1.3 across locations. The intercropping advantage was greater in the wetter, southern zone than the central zone. When the traditional (farmer) system was compared with the improved system, substantial groundnut yield gains were observed in the improved system. Cereal yields remained unchanged, while groundnut yields were about 50% greater in the pearl millet/groundnut system, and about 100% greater in the sorghum/groundnut system (IER 1981-90). The significant groundnut yield increase without affecting normal cereal yields attracted considerable interest among farmers.

Concluding Remarks

It has now been widely recognized that the "green revolution technology" of Asia and certain other locations does not hold similar potential for the Sahel. Research in sub-Saharan Africa has clearly shown that exploiting favorable genotype-environment interactions in these resource-poor and higher stress areas is difficult. The transformation of traditional agriculture with new plant types that respond to improved levels of management can only be a longer term approach. From the beginning, ICRISAT-Mali has recognized the need for an alternative approach, and has therefore emphasized two agronomic research areas:

- developing production technologies to improve traditional (mixed cropping) systems, and
- working with crop breeders to identify improved, management-responsive cultivars. These distinct research strategies will continue even after the ICRISAT-Mali program has ended.

Working closely with their IER counterparts, the ICRISAT agronomists provided critical support to IER's agronomic research program, and helped to build its institutional capacity. Many Malian agronomists have returned from advanced training, and assumed leadership of research projects. In fact, IER has been recognized as a leading institute in rainfed cropping systems research among its neighboring West African countries. Future research should build on this existing base and focus on intensification of the system for the south and stability of the system for the north. The scientific leadership must be provided by the production agronomists, and plant breeders and other crop improvement scientists should be encouraged to develop the cultivars needed to fit into these various systems.

Although ICRISAT-Mali followed a farming systems approach in its research activities, the program was only indirectly involved in on-farm research. It is hoped that in the future the agronomists who are responsible for on-station cropping systems research will also be involved in on-farm research activities related to cropping systems improvement.

During the life of the project, soil and water management research received less emphasis. The major responsibility for this area rested with AGP and some externally funded projects, and it needs further strengthening. Long-term research on soil moisture and fertility management to improve sorghum and pearl millet productivity should receive greater attention. Cropping systems research agronomists in Mali should play a critical role in bringing the plant and soil scientists closer to developing improved production systems on a sustainable basis. Technologies to arrest degradation of crop land, build soil fertility through crop rotation, enable water harvesting, and develop appropriate tillage systems to conserve soil moisture and build soil structure are known, but a massive program of adaptive and applied research is needed in these critical areas.

Research on crop-livestock integration has not received enough emphasis. Mali has about 40% of the draft animals in West Africa, and animal traction is very important to the country and its agriculture. Research on animal traction to develop appropriate low-cost equipment should receive more attention. The role of animals in both the enhancement of soil fertility and degradation of soils should be quantified for developing appropriate crop-livestock systems in the rainfed farming areas. The overall objective of future cropping systems research should be to increase the productivity of sorghum- and pearl millet-based production systems while improving their sustainability. The mixed cropping systems and rotations of cereals and legumes traditionally followed in Mali could be improved further by including improved cultivars and better soil moisture and fertility management practices.

Section 5

Discussion and Recommendations

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Discussion

The ICRISAT-Mali program has been operating for 12 years. The final evaluation conducted during 1989 concluded that "the accomplishments are many given the small two-man TA (technical assistance) team and reflect the overall success of the project (USAID 1989)."

The mid-term evaluation of the project (DAI 1983) also had similar comments, describing the program as "extremely cost-effective". The evaluation team suggested that "the Mali model may prove to be one of the most viable approaches ICRISAT could follow in the development of its African research and training program." In fact, the SADCC (Southern Africa Development Coordination Conference)/ICRISAT program adopted a similar model on a regional basis for southern Africa.

Project Accomplishments

The final evaluation (USAID 1989) highlighted the following as major accomplishments over the life of the project:

Sorghum Breeding

- Good progress has been made in transferring valuable traits from the local Guineense sorghum varieties to the more productive exotic sorghum varieties. Several have been released as varieties, and others are being used as a base for further varietal improvement.
- Collections of Malian sorghum races conducted by SRCVO, the International Board for Plant Genetic Resources (IBPGR), the Institut français de recherche scientifique pour le développement en coopération (ORSTOM), and the ICRISAT-Mali program constitute an important genetic resource and represent the base from which future breeding progress in sorghum will be attained.
- Improved sorghum varieties with semi-compact heads, shorter stems, good pest resistance, and satisfactory *tô* quality were bred by ICRISAT-Mali. Malisor-7 and Malisor-5 are the most outstanding achievements made to date. They represent a major step in the development of superior genotypes for the low and intermediate rainfall zones.
- Recent tests confirm that Malisor-7 is resistant to head bugs. This is a major breakthrough for Mali and much of Sahelian Africa. Malisor-7 combines head bug resistance and the high grain quality characteristics of the local varieties with improved agronomic characteristics of the introduced exotic varieties.

Pearl Millet Breeding

- The ICRISAT-Mali program established a genetically diverse germplasm base of over 1200 genotypes for pearl millet improvement. Approximately 75% of these accessions are cultivated types. This collection is a valuable national resource and provides an excellent base for future breeding efforts.
- Several improved millet composite varieties have been derived from the recurrent selection breeding program of ICRISAT-Mali: Souna-Sanio, Pool-6, Pool-4, and Pool-9. These form the base for further improvement in pearl millet breeding. Under favorable conditions these pearl millet composites have yielded 25-30% over local varieties. These results have stimulated interest from some of the rural development organizations.
- Use of a perfected method for downy mildew screening shows great promise for identifying sources of resistance. Several varieties have already been identified.
- The improved millet varieties IBV-8001, NKK, and *Toroniou de Ningari* have been extended to farmers in the Segou and Kayes/Koulikoro regions. Adoption studies show these varieties cover more than 15% of the pearl millet area in these zones. Earliness and pest resistance are the factors which contributed to the success of these varieties.

Cropping Systems Research

- Soil management research has shown a consistent positive response to plowing, and frequent positive responses to ridging. These results have played a significant role in current extension efforts, which now encourage the use of animal traction for land preparation.
- Research results on sorghum/cowpea and pearl millet/cowpea intercropping systems show that a 30% yield increase over the corresponding sole crop system can be achieved. On-farm trials of these systems have confirmed experimental results, and they are now being adopted by some farmers in zones where the rural development agencies have extended the systems. In addition, the ICRISAT-Mali team has shown that

choice of varieties for these systems is important to optimize profitability.

- The cropping systems research component developed a maize/pearl millet package which can produce 2000-3000 kg ha^{-1} of maize and 600-800 kg ha^{-1} of pearl millet when properly implemented. The system was tested in farmer fields and showed a consistent increase in total grain yield in the order of 40% over sole-crop yields, and substantially higher than total grain yield in traditional maize/pearl millet systems.
- Intercropping research results have indicated that yields improve if a high groundnut population is maintained and the cereal population is reduced. A significant result of this system is the associated reduction in *Striga* incidence on the cereal crop.
- New systems were developed in the higher rainfall Guinean zone involving relay cropping and ratooning, as well as intercropping to maximize the total production potential in the zone.
- ICRISAT-Mali introduced improved cowpea varieties into the sorghum and pearl millet intercropping systems, which have had a considerable impact at the farmer level.
- Research on crop diversification has shown that both finger millet and pigeonpea can be successfully grown in Mali, although markets for these crops have not yet been developed.

Training

- ICRISAT-Mali provided long-term training opportunities for 11 Malian researchers (Annex I), 6 of whom have now returned and are contributing significantly to research programs.
- The short-term training component sent 59 middle-level researchers and technicians to ICRISAT Center in Hyderabad, many of whom are now an integral part of the research program in Mali on semi-arid crops and cropping systems (Annex II).
- Over the life of the ICRISAT-Mali program, 67 final-year students from Katibougou IPR have completed internships under the guidance of an experienced researcher (Annex III).
- ICRISAT-Mali organized a series of workshops on specific research themes. These workshops increased the level of scientific activity and interaction among an institutionally diverse group of researchers and extension personnel, and has significantly strengthened the linkage between research and extension. The proceedings of these workshops published in French are also serving as important references for scientists of other West African SAT countries.

Infrastructure Development

- The ICRISAT-Mali program played a key role in the development of facilities and personnel training for the Cinzana station, which now serves as a model for the development of other research stations in Mali.
- The construction of a food technology laboratory at Sotuba has added two new and promising dimensions to cereal research in Mali. First, it enabled the Malian national program to become the first West African breeding program to conduct systematic food quality testing as part of its breeding work. Second, the laboratory has taken the lead in developing several processed grain products, which by improving the quality or convenience of pearl millet, sorghum, maize, or other grains, can lead to broader markets in Mali.
- The construction of a cold seed storage facility at Sotuba was funded by ICRISAT-Mali, a facility which is essential to preserve and maintain genetic material.
- ICRISAT-Mali encouraged links between national programs and other donor-supported programs, which has further strengthened national sorghum and pearl millet research.

Factors Contributing to the Success of the ICRISAT-Mali Program

The ICRISAT-Mali program has established a strong research base for sorghum and pearl millet, including both the physical and human resources to sustain the research. The reasons for the success of the program include:

Effective NARS and IARC Relationship

The ICRISAT-Mali program is based on a bilateral model as compared to a center or regional model (Fig. 1). The ICRISAT technical assistance staff was well integrated into the Malian national agricultural research system from the inception of the program.

ICRISAT-Mali staff were considered IER staff, and they followed IER administrative procedures and working hours. This integration engendered mutual respect and open sharing of information, and formed the basis for strong support of the program by highly motivated national staff.

IER and ICRISAT both provided high-quality senior staff who worked well together. Technicians and other support personnel from IER were also of high quality, and ICRISAT provided backstopping to the program through short-term consultants in specific areas.

The strong commitment and excellent partnership of the two institutes resulted in the program being "very cost-effective considering the number of accomplishments for the relatively small investment over a 12-year period (USAID 1989)."

Long-Term Commitment

The program emphasized long-term research on food crops, which conforms with the Malian government agricultural research policy of assigning top priority to food self-sufficiency and security. USAID supported the program over the unusually long period of 12 years, with adequate funding to support the long-term research objectives. This long-term support and commitment have created an effective interdisciplinary research team for the semi-arid tropics, including agronomists, plant breeders, pathologists, entomologists, and food technologists.

Continuity of Small, Long-Term Team

Over the life of the program, the ICRISAT-Mali program has had a small, two-man technical assistance team of an agronomist and plant breeder. This team, however, was supported, when necessary, by short-term consultants from both ICRISAT and IER for expertise in other disciplines.

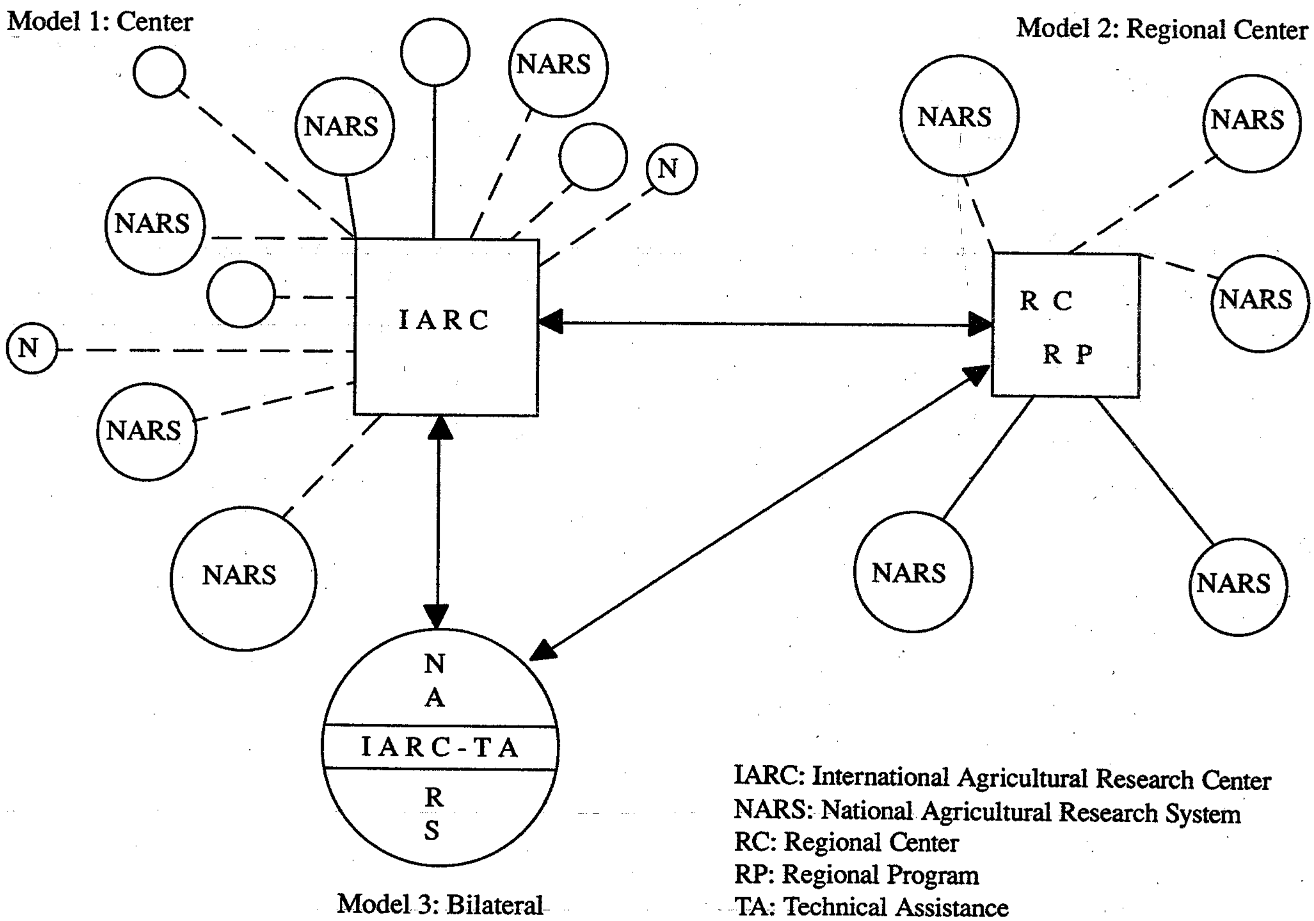

Figure 1. Three models of national and international research partnerships.

The technical assistance staff worked for relatively long periods in Mali (an average of 6 years), and through this staff continuity, they were able to pursue longer-term goals without suffering the disruption that inevitably occurs when new staff arrive (Fig. 2). These long tours by expatriate staff are not very common in donor-funded projects in West Africa. During the 12-year program, there was only one major turn-over of team members.

The small team working for several years has led to a better understanding of research problems, and stimulated collaborative activities with the national staff.

Institutional Strengthening as a Priority

One of the major reasons for the success of the ICRISAT-Mali program has been the immense importance attached from the very beginning to strengthening the research capability of the Institut d'économie rurale. The simultaneous development and reinforcement of research infrastructure and the needed scientific manpower has created a strong foundation for the Institut d'économie rurale to sustain its research activities.

The establishment and operation of the Cinzana station by the ICRISAT-Mali program has been a major element in the development of dryland crop research in Mali, with spillover effects to similar regions of the Sahel in other countries (see Box, the Cinzana Story). Similarly, the development and operation of the food technology laboratory, which has, over the years, become an integral part of the crop improvement program, will make significant economic impacts on alternative uses of cereals.

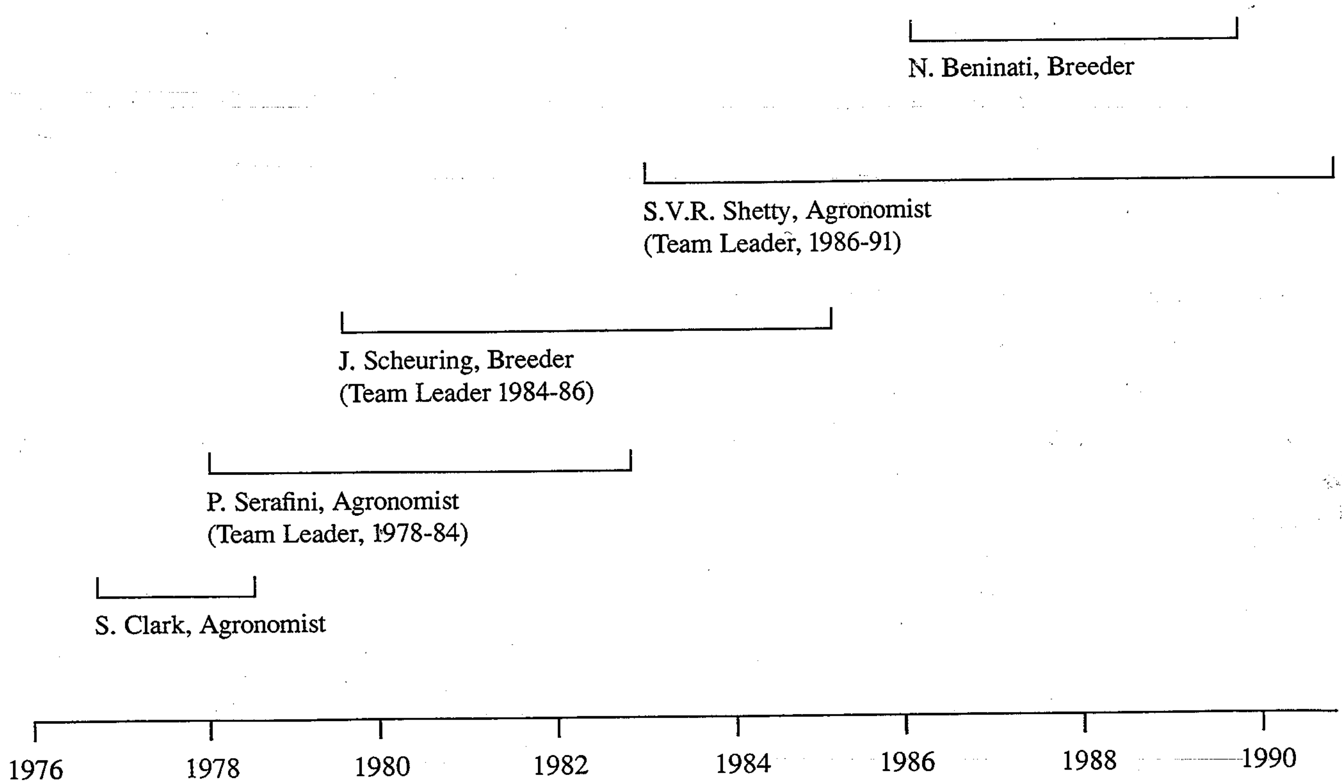

Figure 2. ICRISAT-Mali senior staff over the life of the program.

The Cinzana Story: Model for NARS/IARC/Donor Collaboration?

The final evaluation (USAID 1989) concluded that the ICRISAT-Mali program played a key role in the development of the Cinzana station.

There is no doubt that the development and operation of the Cinzana station has had and will continue to have a great impact on Malian agricultural research. It serves as a model for the development of other research stations in Mali and has allowed scientists to conduct useful research on various dryland crops in an important ecogeographic zone, a capacity that did not exist prior to the project and one which has the potential for "spillover" impact in other countries of the Sahel.

The following chronology illustrates the role of the Cinzana station as a focal point for collaborative research among national and international research and donor agencies, all with an interest in strengthening a national program in Sahelian Africa.

1978	IER invites ICRISAT-Mali to assist in building a major research station in the semi-arid zone	IER/ICRISAT
1979	ICRISAT regional director facilitates Ciba-Geigy Foundation (CGF) contacts with IER and ICRISAT-Mali	CGF
	ICRISAT requests USAID to cofinance the station	USAID
	Soil and vegetation survey	IER/ICRISAT/Texas A&M
1979-83	Station development	GRM/ICRISAT/CGF
1980	Socioeconomic survey lasting 2.5 years establishes technological and sociological profiles and databases around Cinzana	IER/ICRISAT economists
	Exhaustive study of groundwater resources	Swiss hydrological team
	Extensive on-the-job training for station personnel	IER/ICRISAT
1981	Dr Oumar Niangado named station director	GRM
1982	Official inauguration	GRM
	Consultancy on pearl millet breeding	University of Georgia
	Animal traction research consultancies by ICRISAT Center engineers begin	ICRISAT
1984	Drought resistance research	ICRISAT post-doctoral fellow
	Annual soil and water management consultancies begin	CGF/TROPSOILS/ORSTOM/IRAT
1984-87	Plant pathology consultancies, establishment of downy mildew screening facilities	ICRISAT/CGF
1985	Entomology consultancies on head bug research begins	ICRISAT/INTSORMIL
	Crop establishment research consultancy	ICRISAT/INTSORMIL Texas A&M
	Weed science consultancy	CGF

	Sorghum and pearl millet program evaluation	ICRISAT/INTSORMIL
	Annual consultancies on cowpea research and extension	IDRC/IFAD
	Regional pearl millet workshop	ISC/IER
1986	Adoption studies of cowpea varieties	ICRISAT trainee/ Michigan State University
	Soil fertility/toxicity studies	ICRISAT trainee/ TROPSOILS/ Texas A&M University
	Study of *Striga* emergence in intercropping systems	IER/University of Paris/FAO
1988	Research on composting techniques begins	Netherlands Cooperation
	Foundation seed production	FAO/UNDP
	Soil-water balance research begins	IRAT/TROPSOILS
1990	ICRISAT begins transfer of activities to IER	ICRISAT/IER
1991	ICRISAT/USAID withdraws operational funding support. CGF takes full responsibility for funding	CGF/ICRISAT/USAID

The development and sustainability of agricultural research hinges on the development of scientific manpower to foster, direct, and sustain research activities. The emphasis on staff development at all levels as described in Section 2, including the "unique and innovative" training of local agricultural college students, has had a significant impact on the quality of support staff, and the pool from which short- and long-term trainees have been selected.

After establishing a sufficient research base with the necessary infrastructure and scientific manpower, ICRISAT-Mali organized four workshops on specific research themes, which increased the level of scientific activity and interaction with an internationally diverse group of researchers and extension personnel.

These workshops strengthened weak local linkages between research and extension and acted as a catalyst for increased sorghum, pearl millet, and cropping systems research in Mali. The program also encouraged IER researchers to participate in regional and international research networks, which has also strengthened sorghum and pearl millet research activities, considered among the stronger programs in the region. The first-term chairmen of the steering committees of the regional sorghum and pearl millet research networks are from the Malian national program.

Activities such as these to strengthen NARS are not normally a major activity of an IARC. Traditionally such activities are undertaken by donor agencies without the input from national researchers, who benefit from such support. The agronomist and plant breeder, with assistance from IER researchers, identified the needs, planned, prioritized, and implemented the institutional strengthening activities, thus helping to build the necessary infrastructure for research on semi-arid agriculture in Mali.

Targeting Research Efforts

The program has effectively targeted research efforts to specific agroecological zones, each with an appropriate set of priorities and objectives. Further, by focusing on research in traditional mixed cropping systems, the program was able to demonstrate that it is possible to increase the productivity of traditional systems while retaining their advantages.

The involvement of researchers who developed the technologies in planning and execution of on-farm trials also helped to fine tune them. Many of the technologies developed by ICRISAT-Mali have either been adopted by farmers, or shown themselves to be "extension-ready" through their performance under on-farm conditions.

Research Leadership and Donor Coordination

As the international agricultural research center with the world mandate for crop research in the SAT, ICRISAT assumed the initial leadership role for sorghum and pearl millet research in Mali. The technical assistance staff also acted as liaison with scientists from other agencies and donors involved in research on these two crops and their cropping systems.

For example, ICRISAT staff encouraged the Ciba-Geigy Foundation to contribute to the Cinzana station development and operation, and invited INTSORMIL, TROPSOILS, and the Peanut CRSP to initiate and support research in Mali which have further strengthened the Malian national programs.

While coordinating the research supported by various agencies, care was taken to avoid duplication, exploit complementarity and comparative advantages, and fill in gaps. Examples are the development of head bug screening techniques, alternative food uses, identification of physiological factors affecting stand establishment, soil and water management, and cowpea research supported by agencies other than ICRISAT (which did not have a comparative advantage in these areas). All were closely integrated with the ICRISAT-Mali program.

Constraints

The ICRISAT-Mali program has considerably strengthened IER through training and infrastructure development, and helped develop technologies that can increase sorghum and pearl millet production, but some constraints should be noted for consideration in any future cooperative programs.

Poor Reasearch-Extension Linkage

One of the basic design assumptions for the ICRISAT-Mali program was that the Malian extension infrastructure would be able to effectively transfer technological developments to farmers. Some results from the program–technologies and varieties–have not reached the farmer level, and thus feedback from farmers has not been available to researchers. The existing research-extension link outside the CMDT zone is very weak.

An effective model of strong linkages between research, extension, and teaching should be developed to encourage effective transfer of technologies. The on-farm research and multilocational testing units of IER need to be strengthened to improve the linkages between research and extension. Communication between researchers and extension personnel needs improvement.

Poor Linkages Between Socioeconomic and Agricultural Research Divisions

Other factors related to the poor adoption rate for technologies are socioeconomic, such as input:output price ratios, market or demand elasticity, farm incomes, levels of animal traction use, and labor availability. The present research structure does not encourage effective interdisciplinary research by economists and biological scientists.

A well-structured interdisciplinary commodity research team should comprise economists to assist in identifying farmer constraints, on-farm testing of technologies, and advice on policy changes. An appropriate model for technology transfer is needed to improve the adoption rate of agricultural technologies.

The recent plan to reorganize IER, emphasizing regional research, interdisciplinary approaches, and the involvement of extension agencies in prioritizing research should help overcome this major problem in technology development and transfer.

Inadequate Numbers of National Staff

Although training has been both a major activity and strength of the ICRISAT-Mali program, the present staffing levels are still inadequate to sustain research. For example, not emphasizing the need for advanced degree training of the key pearl millet and sorghum breeding positions at an early stage was an oversight.

With the departure of some qualified Malian breeders to administrative positions, the sorghum breeding program is not fully staffed. A similar lack of fully qualified staff also exists in plant pathology, food science, station management, and production agronomy. It will be some years before these gaps are filled by the Malian research staff who are currently working on advanced degrees.

Mali has one agriculture college, which offers only a B.S. degree. There is no institution offering advanced training leading to the M.S. and Ph.D. degrees. In addition, the link between the existing college and research and development agencies is weak. To develop the necessary scientific manpower, academic institutions offering graduate level courses should be established, and the link between teaching and extension should be strengthened.

Lack of Cost-Benefit Analysis and Research Prioritization

The program did not attempt to develop research budget allocations by crops, discipline, or experimental themes early enough. As a result, there is little data for cost-benefit analysis and future research prioritization. Priority research areas such as marketing impact studies (essential for understanding and improving the transfer of technologies), incorporation of organic fertilizers (low-input technologies), seed quality and seed production problems, etc. should have received more attention during the earlier phases of the program.

Additional Constraints

Several other factors also contributed to difficulties encountered by program personnel. Examples include:

- Weak collaborative research links between crop and animal researchers.
- Different expectations by the three different collaborating institutions, IER, ICRISAT, and USAID, each of which did not necessarily have the same mandate, and had different administrative structures.
- Duplication of efforts and difficulty in coordinating some research and development activities because too many donors and external agencies were involved.
- Uncertain long-term funding resulted in too many short-term field trials, and less emphasis on long-term research on sustainability issues.
- Research materials and equipment not available in local markets.
- Lack of good administrative support for program scientists.

Recommendations

Prioritization and Regionalization of Research

The sorghum- and pearl millet-based systems in Mali vary with the agroecological zones in which they are cultivated. Production constraints also have regional differences. Systematic documentation of these constraints should precede interdisciplinary efforts to solve them. The system of centralizing all research in one place should be discouraged, and interdisciplinary regional research should address problems on ecological zones and priorities.

IER has already undertaken the reorganization and regionalization of its research activities. Livestock research previously administered by a different ministry is now part of IER. Regional research centers with their associated stations have been identified, and priority research programs and projects designed. These encouraging developments will enable researchers, administrators, and donor partners to focus on priority research. ICRISAT-Mali staff has participated in this reorganization and prioritization of research.

Sotuba and Cinzana research stations have been identified as the centers of research on sorghum and pearl millet, respectively, where research on varietal development, cropping systems, and crop protection will be concentrated. Farming systems research teams, including livestock scientists and on-farm research agronomists, are also based at these stations to form an interdisciplinary team. Other research centers where some aspects of sorghum and pearl millet research and testing technologies, should be conducted include Mopti (Koporo), Kaye (Kita, Bema), and Sikasso (N'Tarla and Bougouni).

Sorghum and Pearl Millet Breeding

Plant breeders should develop sorghum and pearl millet cultivars which are suitable to intensify and extend these cereal-based cropping systems in southern Mali, and stabilize the systems in the central and northern regions. Identifying cultivars which are resistant/tolerant to the physical and biological stresses prevalent in Mali should be emphasized.

- Sorghum breeding activities should concentrate on pedigree breeding (about 60%), population improvement (30%), and hybrid development (10%). The pearl millet breeding program should continue current population improvement via S_1 recurrent selection, but efforts on single cross hybrids should be minimized in favor of topcross hybrids.
- Selection for yield stability should take a higher priority in both the pearl millet and sorghum breeding programs. Testing advanced material under low and moderate input levels to derive a stability index should be considered.
- More emphasis should be placed on the development of efficient screening techniques for disease, insect, and *Striga* resistance. Cooperative work with ICRISAT regional programs in Niamey and Samanko and INTSORMIL should be encouraged.
- It is recommended that the sorghum and pearl millet breeders work very closely with systems agronomists to identify constraints to varietal adoption and appropriate varieties suitable for various cropping systems.
- The breeding programs should make fuller use of the food technology laboratory for end-use quality evaluations as a routine part of the variety development program. Collaborative research on possible alternative uses for sorghum and pearl millet should be initiated.
- The breeding programs should develop an integrated system of seed multiplication that ensures high quality foundation seed for development and extension organi-

zations. The use of off-season irrigated seed multiplication should be encouraged.

- A well-defined procedure for variety release should be developed. The suggested procedure should clearly indicate the number of test years of advanced materials, disciplines involved in on-station and on-farm testing, procedures for establishing researcher committees to name and release varieties, responsibilities of the foundation seed section to multiply and certify seed, and the role of the department of agriculture in large-scale seed multiplication.

Genetic traits within the Guinea group of sorghums including vigor, stress resistances, stalk strength, and photoperiod sensitivity have contributed significantly to improved cultivars within the ICRISAT-Mali sorghum breeding program. The ICRISAT West African regional sorghum improvement programs should take advantage of these materials and consider incorporating them into their breeding programs.

Agronomy and Cropping Systems

The task of developing improved technology for sorghum- and pearl millet-based systems which suffer from various stresses during the growing season is highly challenging. In Mali, as in other sub-Saharan countries, long-term scientific leadership should be provided by systems scientists (agronomists and soil scientists), working in close collaboration with plant breeders, crop protection scientists, and economists.

It is clear from recent research on rainfed food crops that crop management (and not crop genetics) is the principal factor limiting productivity of cereals in Mali. Within this context, low fertility is the major constraint to improved crop yields. In the absence of added fertility, there is little that can be done through other agronomic practices to increase crop production. In the absence of new technology, which generally includes some "exogenous" inputs, farmers, in general, are using their resource base as efficiently as is possible. Efficiency and effectiveness over time, i.e., sustainability, are appropriate issues and should receive increasing attention.

Results from the Farming Systems program in southern Mali show that weeds are a major problem for farmers, Weed management is more difficult when fertility does not limit plant growth. If progress is to be made in cereal and grain legume production, future agronomy research efforts should focus on improving the farmer's ability to manage fertility and weeds.

Technology packages to halt land degradation and reverse declining soil fertility should be developed. Technologies involving appropriate integration of crop-livestock systems, efficient water and nutrient harvesting, and building soil fertility through the introduction of legumes into the cropping systems along with the integration of chemical fertilizers should be priorities.

Overall, the agronomy/cropping systems research should not only seek to arrest the downward production trend, but also diversify and improve the system to meet the needs of a growing population on a more sustained basis. The clear research priority should be exploiting the existing potential by emphasizing resource management to improve crop system productivity, complemented by continued efforts to increase genetic adaptation to specific needs.

The present research activities to improve sorghum- and pearl millet-based cropping systems, assist plant breeders with the development of management-responsive cultivars, and develop improved technologies for improved cultivars should continue, with emphasis on the following:

- Past experimental data should be organized by ecological zones, analyzed, and published by research topic. These data are unique and should be presented to a broader scientific audience.
- Research strategies should emphasize economic returns to farmers, which are a prerequisite for farmers to purchase inputs for intensification. However, given the current cost of inputs and the farmers' ability and willingness to invest cash in cereal production, the research emphasis in the cropping systems component should focus on lower-input systems, and in particular on lower levels of cash inputs.
- Longer-term, interdisciplinary cropping systems experiments should replace some current research as it reaches completion. New experiments should focus on longer-term effects of selected cropping systems on soil fertility maintenance, yield stability, etc. These experiments should be conducted under both low and modest levels of inputs, including the use of animal manure.
- The integration of legumes into cereal production needs further emphasis. Research on the role of legumes on soil fertility and soil restoration, and further research on food and feed legumes should be incorporated into cropping systems research.
- Research on soil and water management should receive greater attention. The present work on soil rehabilitation and soil erosion should be expanded. Use of organic matter, including crop residues and farmyard manures, appropriate tillage, contour bunding, strip cropping, etc. should be incorporated into long-term studies on cropping systems. The measures of sustainability such as soil organic matter content and pH should be monitored regularly in such long-term trials.

- Additional efforts should be put into research on multilocational and on-farm trials. Research on the constraints to adoption of cropping systems which have already been examined, and the nature of those constraints and the possibilities for changing them, should greatly influence future research priorities in cropping systems and agronomy. More information is necessary in order to design research projects which could lead to readily adaptable new technologies.
- Multilocational trials need considerable improvement, particularly experimental design and data collection.
- Post-harvest research that aims to increase local or export demand for cereals and legumes need emphasis. It should be noted that demand inelasticity is one of principal factors limiting increased cereal production in Mali and West Africa.

Strengthening National Sorghum and Pearl Millet Research – Sustainability Issues

As indicated earlier, Mali has already undertaken strategic planning of its agricultural research programs. The highlights of this reorganization and strategic planning include linking research to development, regionalization of research networks, determination of research priorities, consolidation of research infrastructure, program focus and program planning, assessing human resource needs, strengthening the institute's overall management capacity, and improving the quality of research.

While IER has come a long way to create a sorghum and pearl millet research capacity of its own, the important requirement now is to build on the established foundation. These issues need particular attention:

- The major problem facing the Ministry of Agriculture is to sustain the efforts of the ICRISAT-Mali project, which has provided approximately $350 000 annually for recurring costs. It is unlikely that IER will be able to absorb these costs in the near future. Donors will need to continue providing operational funds to the research programs so that the research capability so carefully established during the past 12 years is not lost. However, plans must be made for the gradual absorption of these recurring costs by IER to ensure that the research program is sustained.
- Although the project has made significant contributions to training Malian scientists and technicians, major gaps remain. Training should continue to receive major emphasis to prepare young Malian scientists to assume leadership in disciplinary research, but the current staffing situation should be studied to determine if continued technical assistance is needed to fill the gaps on a short-term basis.
- Strong collaborative links between crop and animal scientists in research and extension should be emphasized. Communication between researchers and extension agents should be encouraged by the distribution of workshop proceedings and research bulletins.
- There is an urgent need to improve research policy and management of research. One objective of the policy should be to make research a requirement for development, with an orientation to extension agents and farmers.
- Future donor support should be increasingly directed toward improving the institutional capacity of Mali agricultural research. A more rational division of responsibility should emerge with the national government taking increasing responsibilities for salaries and research-related expenses, and the donors providing support for experiment stations, including field and laboratory equipment and training for rainfed crop research.
- IER should orient its research activities to benefit as much as possible from collaboration with regional and international institutions. While regional programs such as WASIP and ISC must be seen as complementary to IER sorghum and pearl millet programs, the limited scientific and other resources of IER must concentrate in the short term on adaptive and on-farm research and the creation of capacity for broader applied and strategic research. Developing the capacity for basic research should receive less emphasis at this stage. The goal should be to increase returns from future investments in agricultural research.
- IER senior scientists have both contributed to and benefited from international and regional programs and networks. Such active participation by Mali scientists should be encouraged. Regional and international research trials should be considered as an integral part of research on rainfed crops in Mali. Such partnerships will enhance the credibility of both national and international research institutions, not to mention the donors who support these research institutes.

The Malian agricultural research system has already taken initial steps to improve its capability for future sorghum and pearl millet research. Sustaining these efforts in the years to come with its own human and financial resources is a challenge for all those interested in agricultural development in Mali.

Annexes

Annex I. Malian senior researchers who have obtained advanced degrees through the ICRISAT/MALI long-term training program

Researcher	Degree	Discipline	Study period	Institution
Adama Coulibaly	B.S.	Agronomy	1978-1981	California Polytechnic Institute
Moussa Traoré	Ph.D	Physiology	1983-1986	University of Nebraska
Mamadou Doumbia	M.S.	Agronomy	1983-1988	Texas A&M University
Dielimoussa Soumano	M.S.	Breeding	1983-1986	Andhra Pradesh Agricultural University
Samba Traoré	M.S.	Soil science	1983-1986	North Carolina State University
~~Ousmane N. Coulibaly~~	~~M.S.~~	Economics	1984-1987	Michigan State University
Assa Kante	M.S.	Food technology	1984-1987	Texas A&M University
Abdoul A. Sow	M.S.	Soil science	1987-1989	Texas A&M University
Karim Traoré	M.S.	Breeding	1987-1989	University of Nebraska
Minamba Bagayogo	M.S.	Agronomy	1987-1989	University of Nebraska
Boncana Touré	B.S.	Breeding	1988-1990	University Center of Dschang, Cameroun

Annex II. Malian researchers who have undergone short-term training at ICRISAT Center, India

Year	Researcher	Discipline
1976	Adama Coulibaly	Agronomy
	Lassana Tigana	Pathology
1977	Mamadou Doumbia	Agronomy
	Bassirou Keita	Soil and water management
	Moriba Konaté	Crop improvement
	Salif Kanouté	Soil and water management
1978	Samba Traoré	Crop improvement
	Issa Diakité	Crop improvement
1979	Ibrahima Karabenta	Agronomy
	Sibene Dena	Crop improvement
	Moussa N'golo Traoré	Crop improvement
	Bakary Nabé Diané	Crop improvement
	Adama Diarra	Crop production
	Moumouni Traoré	Crop production
1980	Jean-Marie Togo	Engineering
	Yangari Coulibaly	Ressource management
1981	Baladji Keita	Crop production
	Aliou Konaté	Crop improvement
	Kalifa Yattara	Crop improvement
	Kalifa Diakité	Crop improvement
	Seydou Touré	Crop improvement
	Dede Koné	Crop improvement
	Mama Konaté	Agroclimatology
1982	Alassane Daou	Crop improvement
	Boncana Touré	Crop improvement
	Djibril Tangara	Crop improvement
	Sada Sow	Crop improvement
	Teme Niaba	Crop improvement
	Bocar Sidibé	Crop improvement
1983	Binke Diarra	Crop improvement
	Modibo Sibi	Pathology
	Lucien Fomba	Crop improvement
1984	Abdoul A. Sow	Crop production
	Sadio Traoré	Crop improvement
	Soungalo Sarra	Crop improvement
	Fode Diallo	Crop improvement
1985	Boureima Togo	Crop improvement
	Moussa Nabilaye Traoré	Crop improvement

Annex II *Continued ...*

Annex II *Continued ...*

Year	Researcher	Discipline
	Balla Diarra	Crop improvement
1986	Hamidou Sangaré	Crop improvement
	Djigui Dembelé	Crop improvement
	Flakoro Coulibaly	Agronomy
1987	Diakalia Sogodogo	Agronomy
	Issiaka Konaté	Agronomy
	Django Keita	Agronomy
	Gomba Diarra	Crop production
	Habibou Bah	Pathology
1988	Abocar Oumar Touré	Crop improvement
	Boureima Togo	Agronomy
	Gaston Sangaré	Resource management
	Oumar Coulibaly	Agronomy
	Kondjiri Konaré	Entomology
1989	Reffing Konaté	Cropping systems
	Lamine Camara	Crop production
	Lassine Sacko	Resource management
	Fousseiny Traoré	Crop improvement
1990	Famory Tounkara	Crop production
	Binogo Ouologuem	Genetics
	Katilé Seriba dit Ousmane	Pathology

Annex III. Thesis subjects of IPR Katibougou students who have completed internships with the ICRISAT-Mali program

Year and thesis subject	Student
1977	
Cereal/legume intercropping systems in Mali	Baladji Keita
1979	
Survey of sorghum production in the region of Gao	Mamzata Moussa Dialla
A study of *Striga* on sorghum	N'Tji Coulibaly
New species of millet introduced in Mali	Thierno B. Cissé
Sorghum cultivars from the 1978-79 germplasm collection	Seydou Touré
1980	
Culinary acceptability as a selection criteria in sorghum	Salimata Sidibé
Identification of Souna and Sanio cultivated in Mali	Mamoutou Sanogo
Brown layer of grain in local sorghum	Mamourou Diourté
Heterosis effects in Malian sorghum	Aboubacar B. Touré
Intercropping systems in Mali	Abdoulaye A. Sow
Selection of food-type cowpeas in Mali	Kadiatou Niang
Irrigation needs of Gombo	Soumaila Diarra
Growth and development of millet variety M_9D_3	Kecouta Sanogo
1981	
Sorghum *tô* conservation and color	Assa Kante
1982	
Weed control in intercropping systems	Mady O. Sissiko Laye Bagayogo
Characterization of Guinea sorghums	Karim A. Traoré
Interaction of millet phenotypes with density and fertility	Ousmane Sissoko
Effects of auxins on groundnut and vouandzou	Dansa Conté
Variability in millets and sorghums in the the fifth, sixth, and seventh regions	Lassine Sacko
Selection methodology for varietal resistance to seedling drought	Magnan Diarra
Millet selection criteria	Diaby Mamadi
1983	
Sorghum and millet varietal evaluation	Diallo Ousmane Souleymane
Morphologic variability of Malian vouandzou	Noumoussa Soumaoro
Introduction of *Eleusine corocana* in Mali	Moussa Kassambara
Progress in sorghum population breeding	Aliou Hamadou Cissé
Tillage by animal traction in Cinzana	Adama Togo
"Chibras" in millet	Tompa Timbota
Physical and chemical properties of soil	Ramatou F. Maiga
Sorghum response to nitrogen fertility	Modibo Cheick Diallo
Response of millet and maize to molybdenum	Moussa Alassan Diallo

Annex III *Continued ....*

Annex III *Continued ....*

Year and thesis subject	Student
1984	
Response of millet to crop density	Souleymane F. Sylla
Drought resistance in sorghum	Fakoro Kané
Photoperiodism in local sorghums	Dramane Fofana
Nitrogen response in sorghum	Moussa Kané
Radiation resistance on rice germination	Ismaila Mahamane
Effect of irrigation on flowering	Nouhoum Alhoussein
Resistance to radiation of rice	Alhadar A. Halidou
	Moussa Maiga
Striga control	Issa Djouratié Sanogo
Genetics of pearl millet	Diagouraga Mody
Millet grain quality	Aminata Djiré
Heredity of domestication of *Pennisetum typhoides*	Helene Yoly Ichennauser
1985	
Mutation breeding of fonio	Moussa Youssou Traoré
Sorghum breeding in the Sahel	Abdel K. L. Sanogo
Comparison of advanced breeding lines	Aminata Seydou Guindo
Radio-sensitivity of four fonio ecotypes	Belco Oureiba
1986	
Sorghum density and grain vitrosity	Adama N. Samaké
Productivity of sorghum/groundnut intercropping	Kadialy Diawara
Agronomy of sorghum cultivars	Salimou Diarra
Productivity of maize/millet intercropping	Haoua Coulibaly
Tillering as selection criteria of sorghum varieties	Mamadou N'Diaye
Productivity of millet/cowpea intercropping	Sekou M. Koné
1987	
Productivity of sorghum/groundnut intercropping	Aminata Drabo
Production technology of sorghum	Djénéba Tembel
Evaluation of new millet cultivars	Abdoul Karim Soumaré
Yield components in advanced sorghum breeding lines	Aly Bakary Coulibaly
Tillering of sorghum cultivars	Waly N'Diagne
Evaluation of the sorghum base population	Zakaria Coulibaly
F4 breeding line evaluation	Sabine Togola
Evaluation of local sorghum ecotypes	Fatoumata Guindo
1988	
Sorghum breeding methods and procedures	Oumou Djire
Maize/millet and sorghum/groundnut intercropping systems	Houzeimata Maiga
1989	
Preliminary studies on sorghum/pigeonpea intercropping system	Aissata Cissé
Layout and data collection in sorghum/cowpea intercropping trial	Aboubacar P. Diallo
Contribution to the improvement of sorghum/groundnut intercropping system at Sotuba	Mamadou M. Touré
Contribution to the improvement of maize/pearl millet intercropping system at Sotuba	Timothé Guindo
Following the rainy season activities of the sorghum breeding program at the agronomic research stations ofSotuba and Samanko	Moussa Tandia
Studies of sorghum line characteristics drawn from the base population of Cinzana	Abdoulaye G. Diallo

Annex IV. Some short-term technical assistance consultancies by ICRISAT scientists.

Year	Consultant	Discipline
1980	R.W. Willey	Agronomy research
1981, 1983	R.K. Bansal	Animal traction, machinery design and adaptation, training
1981	B.K. Sharma	Planning of Cinzana Station
1980, 1983, 1985, 1988	Anand Kumar	Evaluation of millet program, exchange of materials
1980, 1983, 1987	D.J. Andrews	Evaluation of the millet program
1980, 1981, 1983	J. Peacock	Physiology research
1980, 1987, 1987	L.R. House	Evaluation of the sorghum program
1983	H. Veirich	Socioeconomics of *Eleusine coracana* production
1982	W. Stoop	Agronomy research
1982	J. McIntire	Socioeconomics
1981-1988 (annually)	B. Gilliver	Statistics
1985	P. Soman	Physiology
1985, 1986	S.D. Singh	Pathology
1985-1989 (annually)	J. Werder	Pathology
1985-1990 (annually)	C. Renard	Resource management
1986, 1988	H.C. Sharma	Entomology
1987, 1988	N.K. Awadhwal P.G. Serafini M.C. Klaij C. Giroux	Animal traction Farm management Farm management Communications
1990	T.J. Rego	Soil fertility
1990	S. Beckerman	Communications
1991	R. Stern	Statistics

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Annex VII. Acronyms

AGP	Agropedology
CEMP	Cellule des essais multilocaux et prévulgarisation
CGF	Ciba-Geigy Foundation
CGIAR	Consultative Group on International Agricultural Research
CMDT	Compagnie malienne pour le développement des textiles
CRSP	Collaborative Research Support Project
DMA	Division du machinisme agricole
DAF	Division administrative et financière
DET	Division des études techniques
DDI	Division de la documentation et de l'information
DPE	Division de la planification et de l'évaluation
DRA	Division de la recherche agronomique
DRSPR	Division de recherche sur les systèmes de production rurale
FSR/E	Farming systems research and extension
GDP	Gross domestic product
GRM	Government of the Republic of Mali
IBPGR	International Board for Plant Genetic Resources
IARC	International agricultural research center
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IER	Institut d'économie rurale
ILCA	International Livestock Centre for Africa
INRZFH	Institut national de recherche zootechnique, forestière et hydrobiologique
INTSORMIL	USAID Title XII CRSP on sorghum and pearl millet
IPR	Institut polytechnique rural
IRAT	Institut de recherches agronomiques tropicales et des cultures vivrières
ISC	ICRISAT Sahelian Center
ISNAR	International Service for National Agricultural Research
LER	Land equivalent ratio
ODIK	Opération de développement intégré du Kaarta
ODR	Opération de développement rural
OHV	Opération Haute Vallée
OPSCAR	Operational scale agricultural research
ORSTOM	Institut français de recherche scientifique pour le développement en coopération
PAR	points d'appui de recherche
SADCC	Southern African Development Coordination Conference
SAFGRAD	Semi-Arid Food Grain Research and Development
SAT	Semi-arid tropics
SRCVO	Section de recherches sur les cultures vivrières et oléagineuses
TROPSOILS	USAID Title XII CRSP on Soil Management
USAID	United States Agency for International Development
WARDA	West Africa Rice Development Association
WASIP	West Africa Sorghum Improvement Program

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